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# DYNAMO CONSTRUCTION.

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# DYNAMO CONSTRUCTION

## *A PRACTICAL HANDBOOK*

*FOR THE USE OF ENGINEER-CONSTRUCTORS AND ELECTRICIANS-IN-CHARGE*

EMBRACING

FRAMEWORK BUILDING, FIELD MAGNET AND ARMATURE WINDING AND GROUPING, COMPOUNDING, &c.; WITH EXAMPLES OF LEADING ENGLISH, AMERICAN, AND CONTINENTAL DYNAMOS AND MOTORS

BY JOHN W. URQUHART, ELECTRICIAN

AUTHOR OF "ELECTRIC LIGHT" AND "ELECTRIC LIGHT FITTING"

With Numerous Illustrations

LONDON
CROSBY LOCKWOOD AND SON
7 STATIONERS' HALL COURT, LUDGATE HILL
1891

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# PREFACE.

A FEW words may be given here in explanation of my aim in offering this Handbook of the Dynamo-electric Machine.

Much has been done by several well-informed writers towards disseminating a knowledge of the principles of the dynamo, but I could not attempt to decide whether the course of study laid down by these learned authorities has commended itself generally to engineers. It is, however, beyond dispute, that although the excellent works of two or three English authors have done a great deal towards spreading correct views of the theory of the dynamo, their labours have not covered the technical requirements of ordinary engineers and mechanics. The electro-technical journals of this country, recognising this fact, have of late begun to devote a good deal of attention to the mechanics of the dynamo. They have engaged the best known writers, consisting mostly of practical men, to throw light upon the jealously-guarded "mysteries" of the dynamo-builder's art, and doubtless with great success. But while this important work of instruction is in progress in those journals, there are numerous engineering students who will, no doubt, welcome a fairly complete Handbook upon the subject. It is to this class that I look for readers.

A long practical acquaintance, not only with the subject, but with the kind of men who devote their lives to it, has convinced me that a treatise of the kind, to be acceptable at the outset to the minds of ordinary engineers, must have some of the following characteristics :—It must be very plainly worded ; it should explain as much as possible of the theories of the dynamo in every-day language ; if a theory is adopted, the physical theory by preference should be chosen, and this should be expressed as plainly as the case will permit. Lastly, the treatment of the constructive details should be very practical.

I have endeavoured to carry out these aims in the following pages, and I earnestly hope that the book may satisfy the expectations of the many kindly readers of my treatise on "Electric Light" who have expressed a desire to see a work by the same author on the Dynamo.

The Introduction contains a condensed history of the subject ; the salient features of dynamo-electric theory are touched upon in the first and second chapters ; and the remainder of the work is devoted to technical expositions of the "build" of various kinds of machines, including chapters descriptive of typical dynamos and motors. The illustrations, with one or two exceptions, are original, and have been engraved from photographs accurately taken for the purpose.

*May*, 1891.

# CONTENTS.

## INTRODUCTION.

PAGE

DEFINITIONS—A Magneto-Electric Machine—An Electric Motor—Evolution of the Dynamo—Faraday's Experiments of 1831—Earliest Attempts to Devise Magneto Machines—Faraday's Disc Machine—Early Attempts to Construct Magneto-Electric Machines—Sturgeon's Armature—Stöhrer's Machine of 1836—Woolrich's Machine of 1841—Wheatstone and Cooke's Improvements—Suggestions of Sören Hjorth—Brett's Improvements—The "Alliance" Electric Light Magneto Machine—Siemens' Shuttle Armature—Wilde's Improvements—Development of the Self-Energizing Principle in Dynamos—The Term "Dynamo-Electric Machine"—Non-Fluctuating Current Gramme Armature of 1870—The Alteneck Armature—Further Improvements in the Dynamo—The Return to Alternating Currents—Sir William Thomson's Suggestions of 1881—Development of Constant Potential Working—Improvement in Brush's Armature . . . 1

## CHAPTER I.

### ELEMENTS OF THE DYNAMO.

CHIEF PARTS OF THE DYNAMO—Simplest Conception of a Dynamo—The Field Magnet—The Simplest Armature—The Collector or Commutator . . . . . . . . . . . 20

## CHAPTER II.

### NOTES CONCERNING THE ELEMENTARY PRINCIPLES.

MAGNETIC FIELD—Magnetic Field due to a Current-bearing Wire—Curves of the Magnetic Lines—Diffusion of the Lines—Concentration of the Lines—Magnetic "Leakage"—Physical Significance of the Lines of Force—Magnetic Reluctance—A Magnetic Unit—The Value of the Lines of Force—Lines of Force and a

PAGE

Conductor—Lines of Force in the Field of a Dynamo—Maximum Magnetization—Motion of a Conductor in the Field—The Magnetic Field of a Dynamo—The Armature—The Commutator . 30

## CHAPTER III.

### DYNAMO FIELD MAGNETS.

SEPARATE EXCITATION—Series Winding—Shunt Winding—Compound Winding . . . . . . . . . . . . 41

## CHAPTER IV.

### CALCULATIONS RESPECTING EXCITING COILS.

MAGNETIZING POWER OF A CURRENT—The Permeability of Iron to Magnetism—Dr. Rowland's Researches—A Curve of Magnetization—Electro-Magnet Formulæ—Modern Conception of a Magnetic Circuit—Ohm's Law and the Magnetic Circuit—Magnetic Saturation—Field Magnet Coils—Trial Method of Determining Magnet Winding—Magneto-Motive Force . . . . 53

## CHAPTER V.

### DETAILS RESPECTING EXCITING COILS.

TABLE OF CURRENT DENSITIES AND SECTIONAL AREAS OF DYNAMO WIRES—Length of the Bobbins—Field Magnet and Armature Insulated Wire—Operation of Winding . . . . . . 70

## CHAPTER VI.

### FORM OF THE FIELD MAGNET.

SINGLE CIRCUIT MAGNETS—Cast-iron Field Magnets—Edges and Corners—The Efficient Section of Core is undoubtedly a Circle—Pole Pieces—The Armature Chamber or Bore—Consequent Pole Magnets—Cast-iron Magnets—Right and Left-handed Coilings—Direction of the Helix Cross-Connections . . . . . 79

## CHAPTER VII.

### THE ARMATURE.

REVOLUTION OF IRON CORE NOT NECESSARY—Means of Superseding the Iron Core — Commutator — Continuous Current Armature . . . . . . . . . . . . 91

## CHAPTER VIII.

### THE ARMATURE CORE.

PAGE

LAMINATION OF THE IRON—Foucault or Eddy Currents—Heat of Core, or Eddy Currents in, Detrimental to Magnetic Induction—The Laminations—Lamination of Drum Armatures—Lamination not without Disadvantages—Lamination of Ring Armatures—Gramme Armature—Influence of the Pacinotti Projections—Material of the Armature Cores—The Core regarded as a Link in the Magnetic Circuit—Cross Section of the Core—Rules appertaining to Armature Cores—Classification of Armature Cores—Drum Armatures—Ring Armatures—Spherical Armatures . . 102

## CHAPTER IX.

### ARMATURE WINDING.

FORMULÆ OF ELECTROMOTIVE FORCE IN ARMATURE—Determination of the Current—Proportion between Depth of Windings and Diameter of Core—Measurement of Magnetic Lines through Armature . . . . . . . . . . . . 118

## CHAPTER X.

### RING ARMATURE WINDING.

CONTINUOUS HELIX METHOD—Insulation of the Core—Rotation Mounting of the Core—Coils of the Helix—Breakdown of Insulation—Operative Details of the Winding—Causes of Sparking—Collector for Symmetrically Wound Ring—Collector Brushes for Ring Armature—Typical Ring Armature Dynamo Dissected—Winding Ring for a Multipolar Field—Multipolar Windings—Square Section Wire for Armature Winding—Cylinder Ring Winding—Fan Spokes of the Star Wheel—Driving Horns—Manipulation of Heavy Conductors—Ring Armature with Open Coil—Spherical Armature . . . . . . . . . 125

## CHAPTER XI.

### DRUM ARMATURE WINDING.

DIAGRAMMATIC VIEWS OF CYLINDER OR DRUM WINDINGS—Drum Windings in General Use—Dividing the Coils—Drum Armature with Frölich Windings—Windings for High and Low Tension—

PAGE

Testing for Short Circuits—Various Devices for Neutralising Eddy Currents in Drum Armature—Heating of the Pole Pieces—Ventilation of the Armature—Turns in Multiple Arc in Armature—Current Density in the Wires—Depth of the Air Gap—"Dead" and "Active" Wire on the Armature—Circumferential Speed of Armature—Lines of Force per Watt—Cross Section of the Armature Conductor per Ampère—Percentage of the Diameter of Armature Occupied by Windings—Low Resistance Drum Armatures—Circumferential Speed of Armatures—Yards of Conductor per Volt of Electromotive Force—Alternating-Current Armatures—Iron-Cored Bobbins—Coil, Ribbon, and Loop Alternating-Current Armatures—The Coils—Ferranti's Alternator—Drum Alternator Armature—Ring Alternator Armature—Alternator Collectors—Machine without Collectors or Commutators—Unipolar Dynamo . . . . . . . . 152

CHAPTER XII.

ECONOMIC DESIGN.

THE MAGNETIC LINES—Example I.—Resistance—Fall of Potential in Armature—Percentage Loss of Power—Kapp Lines in Armature Core—Dimensions of Field Magnet Core—Dimensions of Armature Core—Magnetic Reluctance of Field Magnet—Magnetic Reluctance of Air Space—Magnetic Reluctance of Armature—Proportioning of Ampère Turns . . . . . . . 187

CHAPTER XIII.

DYNAMO GOVERNING.

REGULATION BY SHIFTING BRUSHES—Governing by Speed—Governing by Variable Resistance—Variation of the Magnetic Field—Regulation by Varying the Width of the Air Gap—Hand Regulation—Cases of Excitation—Resistance Regulators—Regulation of Series Dynamos—Self-regulation by Shunt Winding—Regulation by Compounding—Regulation by a Composite Field—Constant Current Regulation Impracticable . . . . . 200

CHAPTER XIV.

OUTPUT AND EFFICIENCY.

THE ELECTROMOTIVE FORCE LOST INTERNALLY—Power Absorbed Internally—Horse-Power Transmitted to Dynamo . . . 213

## CHAPTER XV.

### GRAPHICAL RECORDS.

PAGE

ORIGIN OF CHARACTERISTIC CURVES—Setting Out Curves—Squared Paper—Hopkinson's Curve—Electromotive Force and Current Curves—Horse-Power Curves—Characteristic with H.-P. Lines—Curve of External Electrical Activity—Line Representing Internal Resistance—Variable Speed Curve—Graphic Record of Shunt Dynamo—Characteristics from Shunt and Series Coils—Characteristic from a Compound Dynamo . . . . 219

## CHAPTER XVI.

### DYNAMOS IN SERIES AND PARALLEL.

SERIES WORKING OF TWO DYNAMOS—Shunt Wound Dynamos in Series—Parallel Working of Two Dynamos—Series Wound Dynamos in Parallel—Shunt Wound Machines in Parallel—Compound Dynamos in Parallel—Interaction of the Dynamos—Alternating-Current Dynamos in Parallel—Series Running of Alternators Impracticable—Interaction of Alternators—Switching in Parallel—Synchronising of Two Alternators, or Alternators in Step . . . . . . . . . . . 230

## CHAPTER XVII.

### THE DYNAMO IN ELECTRIC LIGHTING.

SEPARATE EXCITATION OF ALTERNATOR—Compensation Excitation of Alternator—Alternators Working Transformers—Alternator and Exciter on One Shaft—Compound Dynamo in Incandescent Lighting—The Shunt Machine in Electric Lighting—The Series Dynamo in Arc Lighting—Number of Arcs Lighted by One Machine . . . . . . . . . . 241

## CHAPTER XVIII.

### OPERATIVE NOTES.

ERECTION OF DYNAMOS—Alignment of Bearings—Handling of Armature—Treatment of Collector or Commutator—Connections of the Circuit—Polarity of the Core—Course of the Current—Belting and Belt Joints—Rope Driving—Faults—Ground Fault—Testing for "Ground"—Circuit Closer and Reverser for Testing—Localisation of Faults—Short Circuits and Dead Breaks—Burnt-out Coils—Short Circuiting of Shunt Dynamo—Distributing Leakage Tests—Failure of Dynamo to Excite or Start—

PAGE
Ribbon Lead as Safety Fuse—Failure of the Residual Magnetism—Points of Best Collection—Position of Brushes—Worn Collector or Commutator—Overloaded Dynamo . . . . . 248

## CHAPTER XIX.

## ELECTRO-DEPOSITING DYNAMOS.

"INTENSITY" AND "QUANTITY" IN ELECTRO-PLATING—Electromotive Force Required in Plating—Table of the Forces—Current Density Required—Table of the Currents—Woolrich's Early Plating Dynamo—Gramme's Electro-Depositing Dynamos—Secondary Current of the Plating Vat—Circuit Interrupter—Baths or Vats in Series—Electro Copper Ore Refining—Siemens Dynamo in Electrolysis . . . . . . . . . 262

## CHAPTER XX.

## TYPICAL DYNAMOS.

THE MACHINES CLASSIFIED—Dynamos of the Gramme System—Gramme's Type Supérieur—Dynamos of the Siemens System—Sautter-Lemonnier Dynamo—Rechniewski's Dynamo—The Desroziers Dynamo—Dynamo of the Société Alsacienne de Constructions Mechaniques—Brush's Dynamo—Edison's Dynamo—Elwell Parker Dynamo—Kapp's Dynamos—Kapp's Armatures—Curves of Magnetization—Kapp's Central Station Dynamo—Curve of the Magnetization—Kapp's Alternating-Current Dynamo—Ferranti's Alternators—The Dynamos of Deptford—Four Views of these Dynamos—Details of the Construction—Firth's Method of Regulating E.M.F. of Dynamo—Firth's Machine—Width of the Air Gaps and the E.M.F.—Single Coil Field Magnet—Paterson and Cooper's Dynamo—The Thomson-Houston Dynamo—The Spherical Armature Dynamo—Incandescent Light Dynamo—Motor-type Dynamo—Alternating Current Thomson-Houston Dynamo—Composite Winding—The Westinghouse Alternator—Westinghouse's Armature—Safety Device of the Westinghouse System—Tests of the Westinghouse Dynamo . . . . . 271

## CHAPTER XXI.

## THE DYNAMO AS A MOTOR.

MAGNETIC PRINCIPLES OF THE ELECTRO-MOTOR—Immisch's Motor—Sprague's Motor—Ayrton and Perry's Motor—Crocker-Wheeler Motor—The Electro-Motor in England . . . . 330

# LIST OF ILLUSTRATIONS.

| FIG. | | PAGE |
|---|---|---|
| 1. | Early Type of Magneto-Electric Machines | 7 |
| 2. | Circuit Interrupter | 7 |
| 3. | Early Form of the Commutator | 7 |
| 4. | The Induction Coils Combined with the Field Magnet | 9 |
| 5. | Shuttle Armature, Longitudinal and Cross Section | 11 |
| 6. | ,, ,, Complete | 11 |
| 7. | ,, ,, in Field of Six Magnets | 11 |
| 8. | ,, ,, Cross Section in Field of Magnet | 11 |
| 9. | Magneto-Electric Machine with Shuttle Armature | 12 |
| 10. | Short Shuttle Armature for Small Currents | 12 |
| 11. | Diagram Illustrating principle of Gramme's Ring Armature | 16 |
| 12. | Diagram Illustrating the "Overtype" of Dynamo | 21 |
| 13. | Section of the Collector Bars | 26 |
| 14. | The Collector and Brushes | 26 |
| 15. | Two Part Commutator | 27 |
| 16. | Overtype of Dynamo Depicting the Leading Features | 28 |
| 17. | Electro Magnet of the Common Type | 42 |
| 18. | Rheostat or Regulator of Resistance | 43 |
| 19. | Diagram showing separate Excitation | 44 |
| 20. | ,, of the Series Winding | 45 |
| 21. | ,, showing the Shunt Winding | 47 |
| 22. | ,, of Compound Winding | 50 |
| 23. | Gramme Type of Field Magnets | 87 |
| 24. | Siemens Horizontal Type of Field Magnets | 87 |

FIG. PAGE
25. Type of Alternating-Current Dynamo Field Magnets in General . . . . . . . 87
26. Brush Type of Field Magnet . . . . 87
27. Thomson-Houston Type of Field Magnet . . 87
28. Mather and Platt Type ("Manchester" Dynamo) . 88
29. Alternator Field Magnets . . . . . . 88
30. Single Coil Magnets, Kennedy's Dynamo . . 88
31. Morday Alternator Type Field Magnets . . 88
32. Course of a Current around Magnet . . . 89
33. Diagram of Single Loop Armature in a Magnetic Field . . . . . . . . . . 92
34. Diagram of the Currents in Single Loop Armature . 92
35. Impulses due to One Loop in Armature . . 97
36. " " Two " " " . . 97
37. " " Four " " " . . 97
38. Armature of Alternator . . . . . . . 100
39. Disc from Ribbed Armature Core . . . 106
40. Ribbed Armature Core . . . . . . 106
41. Ring Core of Gramme Armature . . . . . 108
42. Cylinder or Elongated Ring Core . . . . . 109
43. " Ring with Driving Spider . . . . . 109
44. Ring Core with Pacinotti Projections . . . 110
45. " Armature and Collector . . . . . 124
46. " " Connections . . . . . 124
47. Complete Ring Armature . . . . . . 124
48. Collector Bar and its Insulation . . . . . 133
49. Details of the Single Brush Yoke or Rocker . . 136
50. " " Multiple Brush " " . . 137
51. Complete Cylinder Ring Armature . . . 138
52. The Brush Rocker . . . . . . . 138
53. The Base, Bearings and Field Magnets . . . 139
54. Cross Connection of Opposite Coils . . . 140
55. Windings of Multipolar Ring—four Brushes . . 142
56. " " " " two Brushes . . 143
57. Section of Driving "Spider" . . . . . 144

FIG. PAGE
58. Diagram of End of Drum Armature . . . . 154
59. Edison Winding . . . . . . . 155
60. Siemens (Alteneck) Winding . . . . . 156
61. Diagram of various Drum Armature Windings . 156
62 „ of Weston's Windings . . . . 156
63. Section Across Weston's Drum Armature . . 158
64. Diagram of Dr. Frölich's Drum Winding . . 159
65. Course of the Conductor in a Drum Winding . 162
66. Right and Left-handed Arrangement of Alternator Coils . . . . . . . . . 176
67. Coils in Series . . . . . . . . 179
68. „ „ Multiple Arc . . . . . . 179
69. „ or Cells in Series . . . . . . 180
70. „ „ „ Multiple . . . . . . 180
71. Intermediate Arrangement . . . . . 180
72. Wilde's Commutator for Alternating . . . 184
73. Characteristic Curve . . . . . . . 222
74. „ with H.P. Lines . . . . 224
75. Characteristics from a "Compound" Dynamo . 228
76. Characteristic of a Compound-wound Dynamo . 229
77 and 78. Two Forms of Circuit Closer for Testing Purposes . . . . . . . . 254
79. Current Reverser for Testing Purposes . . . 254
80. Diagram of Gramme Dynamo (Type Supérieur) . 272
81. Section of Gramme Dynamo „ „ . 273
82. Sautter-Lemonnier Dynamo . . . . . 275
83. Diagram of Brush's Dynamo . . . . . 279
84. The Edison-Hopkinson Dynamo (English Type) . 280
85. Elwell Parker (Overtype with Fly Wheel) . . 282
86. Kapp's Overtype Dynamo (Longitudinal Section) . 283
87. „ Dynamo (Transverse Section) . . . 284
88. Armature of Kapp Dynamo (Longitudinal Section) 285
89. Curves of Magnetisation . . . . . . 286
90. Kapp's Overtype Dynamo (General View) . . 287
91. „ Central Station Multipolar Dynamo . . 288

FIG. PAGE
92. Characteristic from Kapp's Central Station Dynamo. 290
93. Kapp's Alternator (General view) . . . 292
94. Ferranti Alternating-Current Dynamo . . . 295
95. „ Dynamo open for Examination . . 296
96. „ „ with their Engines . . . 297
97. Marine Type Driving Engines of Ferranti Dynamo. 298
98. Ferranti Dynamo Open, Showing Armature and Field Magnets . . . . . . . . 299
99. Bobbin of Ferranti Armature . . . . 300
100. Details of the Bobbin Holder . . . . 300
101. Armature incomplete, showing Method of Mounting the Bobbins . . . . . . . . 301
102. Connections of the Coils . . . . . 302
103. View of the Collectors and "Leading off" System. 303
104. Ferranti Dynamo (Longitudinal Section) . . 304
105. Firth's Dynamo with Separated Magnets and Sliding Regulating Gear . . . . . . 305
106. Diagram of Kennedy's Single Bobbin Dynamo . 308
107. Thomson-Houston Compound Wound Dynamo . 309
108. „ „ Overtype Bipolar Dynamo . 311
109. „ „ Alternating Current Self-exciting Dynamo . . . . . . . . . . 314
110. Westinghouse Armature . . . . . . 317
111. Armature Coil . . . . . . . . 318
112. Westinghouse Armature (Longitudinal Section) . 318
113. Diagram of the Tatham Dynamometer . . . 326

# DYNAMO CONSTRUCTION.

## INTRODUCTION.

*Definitions.*—The word "Dynamo" has by the force of common usage become equivalent to the longer term Dynamo Electric Machine. But, as employed in connection with Electricity, the abbreviated form is not likely to cause confusion. In the light of the rapid improvements of the past five years it seems unfortunate, however, that so apt a term as Dynamo Electric Machine should have only a limited application to electric generative machines.

Although it was originally proposed by Dr. Werner Siemens to distinguish an important development in the earlier form of power electrical machines, and served the purpose very well at that time, yet the progress of electrical invention exhibits at the present day greater differences between two "dynamos" than ever existed between the early magneto-machine and its self-energizing offspring.

*Any machine moved by mechanical means, and adapted to convert the power of motion into the energy of electricity, may be called a dynamo.*—The older magneto-electric machines effected nothing less than this, yet, *A Magneto-Electric Machine*—an apparatus in which steel magnets are used to furnish the "magnetic field"—is not strictly, by common consent, regarded as a dynamo.

A dynamo is really a magneto-electric machine in which the "field" is maintained by that form of iron magnet called electro, *the electro-magnet being "electrified" or excited by the current of the machine itself.*

Magneto-electric machines are an almost obsolete type. Every year renders the distinction between them and dynamos less marked, and they are gradually becoming recognised as merely an old-fashioned pattern of dynamo.

The duty of the dynamo is the conversion of one form of energy into another form of energy. But it has been discovered that a dynamo is a reversible machine. When it is driven by a steam engine it returns a large proportion of the power expended upon it in the form of an electric current. When, on the contrary, the dynamo is "fed" with an electric current, it becomes itself a *motor.*

*An Electric Motor* is merely a dynamo with its function reversed. While in the first sense it is dynamo-electric, in the second sense it becomes electro-dynamic. A dynamo may thus be regarded as a machine which is adapted either to convert mechanical energy into electricity, or electrical energy into mechanical power.

## Evolution of the Dynamo.

The history of dynamic electricity may be said to date from the year 1831. In that year Dr. Faraday made public several new facts relating to the correlation between electricity and the magnetism of soft iron.*

In the published results now so well known, two important experiments, amongst others, are detailed bearing upon the principles of obtaining electricity from common magnets. Faraday believed that, as magnetism could be conferred upon soft iron by causing an electrical current to circulate around it, the converse of this must be true, and that currents could be obtained by means of magnets.

*Faraday's Experiments of* 1831.—The most striking experiment consisted in wrapping around a soft iron bar a considerable number of turns of insulated wire and connecting the extremities of the coil to a "galvanometric multiplier,"—what is now known as a simple galvanometer or detector of current. When the free extremities of the iron bar were brought suddenly in contact with the poles of a common magnet, an electrical impulse flowed through the coil, causing a deflection of the galvanometer needle to one side. Again, when the bar was pulled away from the magnet, another electrical impulse occurred, but opposite in direction, as shown by the deflection of the needle to the opposite side. It was unnecessary to cause the bar to come into contact with the magnet; motion of the bar to or from its poles only, resulted in currents being set up in the wire.

Enhanced effects were obtained when an electro magnet was used in place of a steel "permanent" magnet. This was due simply to the superior magnetic intensity of field set up by the electro magnet. Currents were also obtained by using the coil alone, after withdrawal of the iron core. These currents were less marked. All the effects obtained were momentary, or lasted only while the motion was maintained.

---

* *Phil. Trans. of the Royal Society*, Nov., 1831.

The famous *iron ring* experiment published at the same time, exhibited the same facts. In the first experiment, the iron bar and coil were magnetized by being brought in contiguity with the poles of a magnet. A current resulted from the increasing magnetization and a reverse current from its decrease. The iron ring effected this merely in another way. Around opposite sides of an iron ring, several inches in diameter, and an inch in thickness, were coiled two separate lengths of insulated copper wire. The ends of one coil were connected with a galvanometer, and the extremities of the other coil were connected with the poles of a voltaic battery. As soon as the battery current flowed in its coil, the opposite coil showed an electric impulse. Another impulse, opposite in direction, marked the stoppage or rupture of the battery current. Here we have the magnetization and demagnetization of iron causing currents in a circuit of wire surrounding it. Faraday showed that the iron ring might be dispensed with, and one coil merely wound over the other instead. The presence of a core of iron, however, intensified the effects.

*Earliest attempts to devise Magneto Machines.*—Attempts were soon made, as we shall see, to construct upon this principle of the magnetization and demagnetization of iron, *machines* in which the effects might be augmented in force, and rendered as nearly continuous as possible.

The first dynamo-electric machine was constructed upon a rather different principle by Faraday himself[*] He found that, while currents might be obtained by merely bringing a coil of wire under the influence of magnetism, this inductive effect might be rendered *continuous* by some arrangement of a continuous conductor.

*Faraday's Disc Machine.*—From this conception was evolved the celebrated disc machine. It consisted merely of a copper disc, about a foot in diameter, capable of being made to rotate in a vertical plane, its edge passing between the poles of a powerful magnet. In order to collect the current a wire was led from the axis, and another wire was pressed upon the periphery of the disc. These conductors were connected with a galvanometer, as before. Upon imparting brisk motion to the disc, a *continuous* current kept the galvanometer needle deflected. A reverse current marked the reversal of motion.

Here, then, was demonstrated the practicability of two elementary types of electrical machine. The first foreshowed the ordinary dynamo machine, in which an iron core surrounded by a coil is either alternately magnetized and demagnetized, or in which the magnetism is continually changing its position. The second showed the method to be pursued in generating electricity continuously without the intervention of a core of iron.

We cannot in this place follow Faraday further. Reference should be made by the student to the original papers. The elementary principles, as far as they affect the dynamo, are dealt with further on, but many of the interesting early experiments in electro-magnetic induction do not come within the scope of the present pages. Excellent text books are not wanting in which the science of electro-magnetism is ably treated. Nor does it appear even necessary to enter upon such well known facts as those appertaining to the inductive influence of currents upon neighbouring conductors, or to explain that an electro-magnet is composed of a bar of soft iron around which a current is sent circulating. These facts can be studied very fully in any modern treatise, dealing with the laws of electricity and magnetism.

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[*] *Experimental Researches*, vol. i.

### EARLY ATTEMPTS TO CONSTRUCT MAGNETO-ELECTRIC MACHINES.

Scarcely a year passed after the publication of Dr. Faraday's researches, before several attempts were made, in different parts of Europe, to construct some form of generating machine. It must be remembered that at that time the "creation" of electricity, as it was considered, had made but little progress; that the voltaic battery, which in later years became so perfect an instrument, was in a very rudimentary form, and that the desire for some mechanico-electric generative appliance was very intense. The first attempt of which there is published record, appears to have been that of the Abbé Salvatore Dal Negro, professor of Philosophy in the University of Padua.

*Dal Negro's Apparatus.*—A few months after the publication of Faraday's discoveries various attempts were made to construct electrical generating machines based upon his experiments. An apparatus said to have been devised in the year 1830, in which the moveable part was subjected to a vibratory motion, was one of the first of these.[*]

*Pixii's Machine* is generally regarded as the parent of magneto-electric apparatus in the form of machines for evolving currents. This device consisted of a steel permanent magnet, of horseshoe shape, mounted with its poles upwards, and so arranged upon an axis that it could be made to rotate. A similar horseshoe of iron, having coils of insulated wire upon its limbs, was fixed above, so that the poles passed each other in close contiguity. When the steel magnet was caused to revolve, currents were induced in the coils of wire. The currents were reversed in direction twice in each revolution, or when the poles passed the points of strongest attraction. At the suggestion of Ampère, Pixii improved his machine by providing it with a *commutating* device, intended to give the ever-changing currents a constant direction.[†]

Improvements continued to be made in the machine, notably by Ritchie,[‡] by Saxton, 1833;[§] and by Clark. Saxton appears to have been the first to make the steel inducing magnet a fixture, and to cause the wire coils to revolve instead. In Fig I, is depicted the general principle of construction embodied by all these early magneto-electric machines. N and S are the polar extremities of a permanent magnet. In front is mounted upon an axis an electro magnet, consisting of a flat iron yoke piece, with projecting cores of the same metal, over which are slipped spools of insulated wire, connected as represented. The electromotive force set up by such an apparatus depended upon (1) the intensity of the magnetic field, or, briefly, the strength of the magnet; (2) the velocity of rotation, and (3) the number of turns of wire wound upon the iron cores. The induced electromotive force of each impulse might be said to be proportional to these conditions. Saxton and other inventors employed four and more bobbins in place of a single pair. Both Saxton and Clark employed a sliding connection, bearing upon the axis of the revolving part, for the purpose of collecting the electrical impulses into conducting wires exterior to the machine. Clark's machine attracted a great deal of attention, inasmuch as its induction coils revolved not opposite to the polar ends of the magnet, but close to the sides of the poles. The machine was also furnished with a "physiological commutator," for the purpose of administering sharp shocks for medical purposes. The model of this machine is still retained for those purposes.*

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[*] See *Philosophical Magazine*, July, 1832.

[†] *See Ann. Chim. Phys.*, 1832.

[‡] *Phil. Trans. of the Royal Society*, 1833.

[§] *Phil. Mag.*, p. 360.

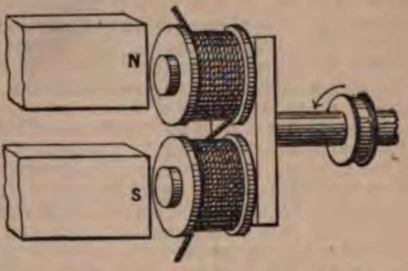

Fig. 1.—Early Type of Magneto-Electric Machines.

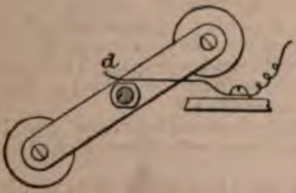

Fig. 2.—Circuit Interrupter.

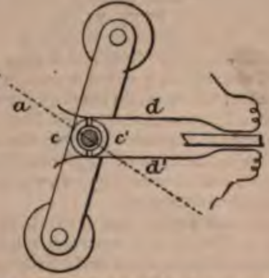

Fig. 3.—Early Form of the Commutator.

In Figs. 2 and 3 are represented, diagramatically, one form of both the physiological and the commutating devices. In Fig. 2, the extremities of the coils were taken to a pair of metallic rings, insulated from, but rotating with the spindle. Upon each of these a fixed spring was caused to press, so as to lead off the current. Only one of these, *d*, is depicted in the diagram. The contact ring under this spring was cut away at two opposite sides as shown, so that contact or continuity was broken twice in each revolution. The effect of this arrangement in the medical machines is well known as an electrical shock. The constant interruption of the current caused the continuous numbing effect. If there should be provided two continuous contacts, there would still exist a strong physiological effect, due simply to the reversal of the currents, as already spoken of.

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* See *Phil. Mag.*, 1836, p. 262; 1837, p. 365, 455.

The simplest device for "commuting" the currents to a continuous direction is depicted in Fig. 3. In this case the extremities of the coils are taken to a pair of half rings, *c c′*, insulated from and rotating with the shaft. Two collecting springs or "brushes," *d d′*, bear upon the rings. The position of the half rings upon the spindle, and the springs with respect to them, were so adjusted that at the instant the armature experienced a reversal of polarity (or current), the half rings would also exchange springs. In this simple manner, spring *d* would always be positive, while *d′* would be negative.

*Sturgeon's Armature.*—Various inventors continued to make improvements in the details of the machine, but the next important step appears to be due to Sturgeon, who constructed an entirely new kind of induction coil for such apparatus. It will be convenient to note that the iron-cored coils used in these machines become known as *armatures*, since, to a certain extent, they served the purpose of the iron "keepers," or armatures universally employed to connect the poles of steel magnets. Sturgeon conceived the idea of concentrating the bulk of his armature, and to secure this end he gave it a *shuttle* shape. But while Sturgeon placed his coil longitudinally between the limbs of the magnet, the full value of this idea was not discovered until Siemens and Halske introduced their famous shuttle armature many years afterwards.[*] Sturgeon also effected improvements in the commutating arrangements.[†] While, as we have observed, Faraday discovered that a metal disc, revolved between the poles of a magnet, yielded a current of electricity, Sturgeon showed that such a disc, when a current was passed from its periphery to its axis, became an electro motor, the disc continuing to revolve as long as the current is continued. Barlow observed the same effect.[‡]

*Stöhrer's Machine* of 1836 consisted of several bobbins of wire, having iron cores, which were caused to pass successively in front of the two poles of a permanent magnet.

It was soon found that a machine could be constructed in which, as in Fig. 4, the inducing magnet, *n s*, might be a fixture, and support upon its poles the soft iron cores and coils, while the armature, consisting simply of a bar of iron, might be caused to revolve. This principle, although it has been carried into the construction of some modern machines, cannot, however, be said to be so successful for the production of electricity as those already mentioned.

Ritchie showed that the iron cores were more effective if in the form of split tubes, and later experimenters have shown that the idea of division may be carried with advantage still further, until the core is formed of a bundle of iron wires. Indeed, the sub-division of the iron cores has become an essential feature in modern dynamo machines for several reasons, to be further explained.

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[*] Specification of patent, 2,017, of 1856.

[†] See *Annals of Electricity*, 1838.

[‡] See Professor Barlow's treatise on *Magnetic Attractions*.

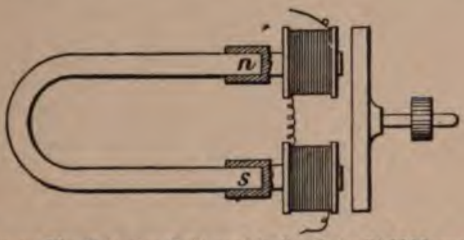

Fig. 4.—The Induction Coils combined with the Field Magnet.

Several patents were taken out for machines, based upon the principle already fully stated, between the years 1836 and 1840, but nothing of fresh interest appears to have been produced.

*Woolrich's Machine of* 1841.[*]—Mr. Woolrich, of Birmingham, constructed a magneto-electric machine for electro-plating purposes, as early as 1841. It consisted of a number of bobbins of wire, having iron cores, fixed to a revolving disc, and passing close to the poles of a number of steel horseshoe magnets. The currents were commuted to a uniform direction. The machine was an extension of the principle of the smaller models already described. It was driven by a steam-engine, and for many years supplied the current required in the plating works of Messrs. Prime. The original machine was shown at the Electrical Exhibition held in Birmingham in 1889. This apparatus was doubtless one of the first, if not the very first, dynamo or magneto-electric machines made for practical purposes, and driven in a regular way by steam power.

*Wheatstone and Cooke's Improvements.*—An important step towards the development of the dynamo machine was taken by Sir Chas. Wheatstone, who, in conjunction with Mr. Cooke, in the year 1845, patented[†] *the substitution of an electro-magnet in place of a permanent magnet in magneto-electric machines.*[‡] Prior to this date, Wheatstone and Cooke effected various improvements in detail in magneto-electric machines for telegraphic purposes. The chief of these is considered to be the employment of a number of armatures in one machine, with appropriate commutators, so that a large number of impulses or currents might be obtained in one revolution, thereby practically producing a continuous current.

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[*] Specification of patent, 9,431, of 1842.

[†] Specification of patent, 10,655, of 1845.

[‡] An electro-magnet consists of a core of soft iron, generally in the form of a horseshoe, having coiled upon each of its limbs a quantity of insulated copper wire. The iron becomes powerfully magnetic, for the time being, when a current of electricity is passed through the coils. Electro-magnets are much more powerful than permanent magnets.

*Suggestion of Sören Hjorth.*—But a far more significant improvement was yet to be effected; the germ of the true dynamo-electric principle as it is generally understood. The honour of first suggesting the idea of *exciting the field magnet of the machine by the current evolved by the machine itself* appears to be due most clearly to Sören Hjorth, of Copenhagen, who published* his invention of the principle in the clearest way, giving drawings. The machine of Hjorth was chiefly remarkable in being furnished with an electro-field magnet, through which the current, when once started, was caused to circulate—forming an apparatus doubtless adapted to work on the principle known as *mutual accumulation* up to the magnetic saturation of the iron. The only way in which the dynamo of Hjorth differed from most machines of the present day appears to lie in the provision within it, in addition to its iron field magnet, of a small steel magnet intended to give the *initial* current, after the manner of the older magneto machines. The originator of this remarkable improvement was probably not aware of the fact that, provided the iron of the electro-magnet were hard enough to retain a little of its magnetism residually and permanently, that alone would suffice to give the machine the required slight starting current, without having recourse to a permanent steel magnet at all.

*Brett's Improvements.*—A few weeks prior to the patent of Hjorth, Brett obtained a patent† for an improvement almost equally remarkable. In this machine, which was of the usual magneto-electric type, with steel magnets, the current from the machine itself, or a portion of it, was led around coils encircling the field magnet, so as to augment its force.

It is remarkable that the publication of this vital principle did not appear to excite much curiosity amongst makers of large magneto-machines. On the contrary, it was allowed to lie neglected for a period of nearly twenty years.

*The "Alliance" Electric Light Magneto Machine.*—Inventors continued, notwithstanding the invention of the dynamo-electric principle, to improve and enlarge the simple magneto-machine, and in the year 1850 Nollet, of Brussels, built a large magneto-machine with the view of decomposing water for the production of oxygen and hydrogen for the lime light. Ultimately, this machine was improved by Van Maldren and Holmes with a view to adapt it for producing an electric light for lighthouse purposes. Several machines were made in Paris after the model adopted by Nollet and Holmes, and were used for many years in the French lighthouses. The construction of the machine exhibits merely an extension of the simple magneto apparatus already described. A large number of bobbins of wire, having iron cores, were attached in two rings, one upon each face of a large metal disc. This disc was caused to rotate by means of a horizontal axis or shaft, geared to a steam engine. The exciting steel magnets were ranged in two groups on either side of the wheel, and in close proximity to the moving bobbins. In the larger machines several such systems were combined. The alternating currents produced were led direct to the electric lamp.

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* Specification of patent, 12,295, of 1848.

† Specification No. 12,054, of 1848.

*Siemens' Shuttle Armature.*—The shuttle form of armature, previously mentioned, was re-invented by Werner Siemens, of Berlin, and patented in England in 1856.* It was at first used mainly for telegraphic purposes, in magneto machines of miniature dimensions, but later on by several makers in machines of the largest class.

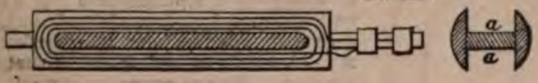

Fig. 5.—Shuttle Armature. Longitudinal and Cross Sections.

This arrangement is represented in Fig. 5. A bar of soft iron, of the H-like section depicted at *a a*, was mounted longitudinally upon an axis. The wire enveloping it was also longitudinal in direction, as shown in the lengthwise section. The extremities of the wire coil were taken to a pair of collecting rings upon the spindle, as already explained. Or, in some cases, a commutator of the split-hoop form was employed. The complete armature is shown in Fig. 6, where *a*, *a*, represents the enveloping coil; *b*, *b*, brass bands intended to keep it in position; *d*, *c*, the axis and driving pinion; and *e*, *e*, the commutator. The magnetic field was obtained by means of a number of steel magnets, arranged with their poles as in Fig. 7, *n*, *s*, &c. This is still more clearly depicted in Fig. 8, where it is to be seen that the polar extremities were hollowed out to receive, and partially embrace, the armature, *n'*, *s'*. The whole constituted a very powerful arrangement. It has for many years been used in telegraph instruments. This form of miniature machine has also been employed for igniting powder in blasting, gunnery, &c., and for medical purposes. Fig. 9 represents one form of

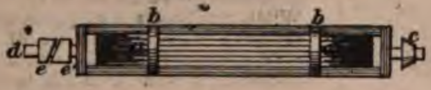

Fig. 6.—Shuttle Armature, complete.

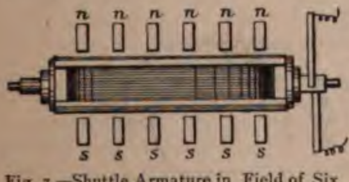

Fig. 7.—Shuttle Armature in Field of Six Magnets—Telegraphic Machine.

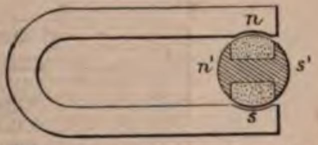

Fig. 8.—Shuttle Armature—Cross Section in Field of Magnet.

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* Specification of patent, 2,017, of 1856.

these apparatus, having a pile of magnets, *a*, furnished with soft iron extension pieces, *n*, *s*, the currents being collected by the brushes, *d*, *d'*, while motion could be given to the armature by the hand-wheel *h* rotating upon the axis *e*. Still another form, in which the short shuttle armature is placed lengthwise within the limbs of a magnet, is represented in Fig. 10. This type has been largely used for furnishing the current for ringing bells, telegraphic signals, &c. A slight to and fro movement of the armature suffices to generate a current.

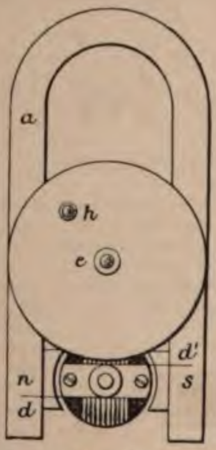

Fig. 9.—Magneto-electric Machine, with Shuttle Armature.

*Wilde's Improvements.*—Amongst others who experimented with the shuttle form of armature was Mr. Wilde, of Manchester, who, in 1863, produced a remarkable combination of a large machine, having an electro field magnet, with a small magneto (steel magnet) machine to provide the current required to excite it.* This combination was by far the most powerful that had hitherto been produced. In a subsequent extension of the same principle, Wilde produced a machine in which a small magneto machine (diameter of armature, 1⅝ inch) excited the shuttle armature of a second (diameter, 5 inches), which in turn provided the current to excite the field magnet of a still larger machine (diameter, 10 inches). The current from this machine or combination, as exhibited at the conversazione of the Royal Society, in 1867, was sufficiently powerful to fuse an iron rod 15 inches in length, and ¼ inch in diameter; and an electric light of enormous power was produced between carbon rods ½ inch square.

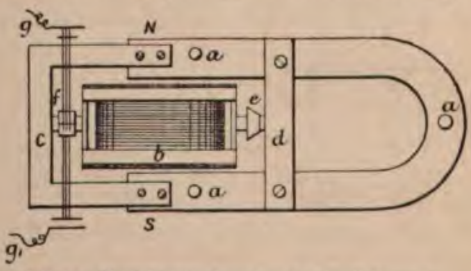

Fig. 10.—Short Shuttle Armature for Small Currents.

Mr. Wilde also produced machines of the disc type, in which a metallic disc, furnished with a horizontal shaft, carried a series of bobbins, with iron cores, upon either face. These were excited, during revolution, not by permanent magnets, as in the "Alliance" machine, but by electro-magnets energized by the current from a small auxiliary magneto-machine.

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* Specifications of patents, 299, 858, 1,994, and 2,997, of 1861; 516 and 3,006, of 1863; 1,412 and 2,753, of 1865; 3,209, of 1886; and 824, of 1867.

*Development of the Self-Energizing Principle in Dynamos.*—As mentioned previously, although more than one inventor had published the self-exciting principle as early as 1848, no application of it had occurred in the machines used for electric light or electro metallurgy up to about the year 1867.

In a remarkable specification of patent,* published in the year 1858, the significant words, "It is proposed to employ the electro-magnet in obtaining induced electricity, which supplies wholly or partially the electricity necessary for polarising the electro-magnets, which electricity would otherwise be required to be obtained from batteries or other known sources," occur. Mr. Murray throws out a suggestion early in 1866,† calling attention to an expedient he had adopted in improving his magneto-machine. He coiled wires around the limbs of the steel field magnet, and led the current from the armature through them in such a direction as to intensify the field magnet, so materially increasing the power of the machine.

The same principle again appears in Baker's patent of 1866,‡ wherein it is suggested that "the currents from the revolving magnets [presumably armature] may be applied to magnetize the fixed magnets." The Messrs. Varley, in December, 1866, filed a patent specification § relating to a machine furnished with an electro field magnet, to be maintained in a magnetized condition by the current from the machine itself. It is specified, however, that the magnet required, at first starting, to be partially energized by the current from some other electric source, and it is not quite clear whether this refers to the mere initial "polarising" of the magnet, which in modern dynamos does not require repetition. Amongst other machines, Mr. S. A. Varley produced a remarkable arrangement, in 1876, in which the field magnet was wound with two distinct wires, one of which was finer than the other, and the circuit of which was always kept closed, while the other was opened several times during the revolution of the armature.‖ This idea appears to be an early step in the development of the important principle now known as *compound winding* in dynamos.

In continuation of our trace of the still more important self-exciting principle, we find that Dr. W. Siemens made a communication respecting it to the Academy of Science of Berlin, in January, 1867; and, a month later, Dr. C. W. Siemens communicated the principle to the Royal Society of London. On the same day, February 14th, Sir Chas. Wheatstone made a communication, almost identical, to the Royal Society. While the principle of Dr. Werner Siemens' self-exciting dynamo provided that the field electro-magnet coils should be connected in continuation, or "series," with those of the armature, that proposed by Sir Chas. Wheatstone suggests that the electro-magnet should be connected in a by-path, loop, or "shunt" circuit, as it is termed. In the first case, the whole of the current evolved by the armature would pass through the magnet coils. In the second instance, a certain proportion only, depending upon the relative resistances of the external and field magnet circuits, would pass by this path. The machine proposed by Siemens would now be called a "series" dynamo; that suggested by Wheatstone, a "shunt" dynamo.

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* No. 2,670, of 1858.

† See *Engineer*, of July 20th, 1866.

‡ Specification 3,039, November, 1866.

§ Specification No. 3,394, of 1867.

‖ See Specification of patent, 4,905, of 1876.

But the importance of these communications to the learned societies, although they doubtless served a good purpose in drawing attention to the development of dynamos was, after all, only secondary, in the light of the repeated publication of the dynamo-electric principle on several previous occasions already cited.

*The Term "Dynamo-Electric Machine."*—Dr. Werner Siemens suggested that the machines in which the self-exciting principle was employed should be known as *dynamo*-electric machines, to distinguish them from the earlier form in which permanent magnets were used, and which still continued to be called magneto-electric machines.

The principle of mutual accumulation, thus brought prominently forward, does not at first appear to be in accordance with the nature of soft iron, but it may be thus concisely stated: If the soft iron field magnet possesses the slightest magnetic polarity, in a *residual* form—and all iron once magnetized may be said to possess and retain it—the feeble magnetic field thus existing in the path of the armature suffices to generate in the coils of the latter a feeble current. This current, being caused to circulate around the field magnet, quickly energizes it so as to strengthen the field; this again re-acts upon the armature, causing it to yield yet stronger currents, which in turn still further strengthen the field; and so on, by mutual re-action, until the field magnet is said to be "saturated," and is thus incapable of being further strengthened. On imparting rotation to the armature of such a machine, on "short" circuit the resistance to motion increases rapidly, and in a few moments either the driving band begins to slip or the coils of the machine become highly heated, and may even be fused.

The enormously greater power of dynamo-machines over magneto-machines, weight for weight, soon caused the abandonment of the steel magnet class, except for a few special purposes.

*Non-Fluctuating Current.*—Hitherto, the best forms of machine, both magneto- and dynamo-electric, were furnished with the improved armature of shuttle shape, first devised, as we have observed, by Sturgeon, and re-invented by Siemens. In the revolution of this armature in the magnetic field, two impulses or short currents were given off during each turn, and however great the velocity of the armature the resulting "current" partook of an intermittent character, or at least might be regarded as a current of rapidly recurring pulsations. Many attempts had been made to overcome this defect, and to produce an armature of such form that the current therefrom would resemble a *fall of water*. One of the most remarkable of these was

*Pacinotti's Ring Armature.*—The invention of this device is believed to date from 1860, but no published account of Pacinotti's machine has been discovered earlier than 1865.[*] The model in which the armature was first used was made for the Physical Cabinet of the University of Pisa, and was at first intended as an electromotor, but its suitability to act as a generator is alluded to by Professor Pacinotti in the clearest way. He says that "that which augments the value of this model is the facility which it offers of being able to transform this electro-magnetic machine into a magneto-electric machine with continuous currents. If, instead of the electro-magnet there was a permanent magnet, and if the transversal electro-magnet [*i.e.*, the ring-like armature] were set turning, one would have made it into a magneto-electric machine which would give a continuous induced current directed always in the same sense." Without knowing it, Pacinotti had invented a self-exciting dynamo machine of a high order of merit, for, if instead of replacing the electro field magnet by a steel magnet, the current from the ring had been merely passed through the field magnet as it stood, the result would have been a series dynamo after the Gramme or Brush pattern.

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[*] See the Italian journal *Il Nuovo Cimento*, xix. p. 378, 1865.

Professor Pacinotti had produced a machine of such form and design that, with the single exception alluded to above, it might even to-day form an efficient model for a dynamo of a superior order. It consists, first of a large electro-magnet, the limbs of which point upwards, and which is fixed rigidly to a base. A vertical shaft is supported midway between the limbs, by the aid of an overhanging cross-piece, clear above the magnet limbs, and upon this shaft is keyed the ring armature. This consists of a ring of iron furnished with sixteen wide tooth-like projections, providing sixteen deep gaps, in which an equal number of coils of insulated wire are wound. The finishing extremity of one coil is connected to the commencement of the next, and so on, the whole of the wire forming in effect a right-handed helix around the ring. From the juncture between each pair of coils a wire is led to one of sixteen segmental brass plates, fitted into a wooden cylinder rotating with the shaft. This part represents the *commutator* from which the currents are collected by two brass springs pressing upon opposite diameters. The springs or "brushes" touch the cylinder in a line at right angles to that joining the magnet poles. In order that the inductive effect of the electro-magnet may be distributed to more than one coil at a time, each pole carries a soft iron extension-piece, or horn, the interior of which embraces the iron ring closely without touching.

The distinguishing merit of the ring armature lies in the fact that it possesses a *continuous core* and a *continuous coil*. There is no break of continuity in either wire or core, [and the resulting current resembles a constant stream, inasmuch as it is free from impulses or fluctuations.

A period of about ten years passed after Pacinotti's invention, during which this beautiful device appears to have been forgotten.

*Gramme's Armature of* 1870.—In the year 1870 M. Gramme, an electrician of the Alliance Company in Paris, independently invented a ring armature* similiar in many respects to that of Pacinotti, but intended primarily for use in a dynamo-electric machine upon the self-energizing principle. This armature consisted of a smooth core of soft iron wire, Fig. 11, completely over-wound with an endless helix of insulated copper wire several layers deep. From a large number of segmental points in the helix connecting wires led to an equal number of commutator plates fixed in grooves in a wooden axis *a*, the current being led away by the brushes *a*, *b*. This ring was mounted upon a horizontal shaft, in a vertical plane, and rotated between the polar extensions of a powerful electro-magnet. The introduction of Gramme's machine (details of which will be found in succeeding pages) gave a great impetus to electric lighting, and may indeed be said to be the initial step towards the general utilisation of the arc light for street illumination.

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* Specifications of patent, 1,668 of 1870, and 953 of 1878.

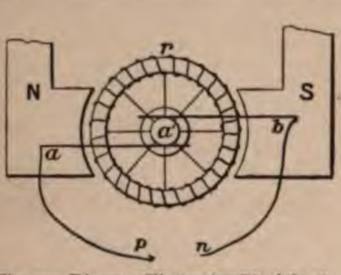

Fig. 11.—Diagram Illustrating Pinciple of Gramme's Ring Armature.

*The Alteneck Armature.*—The next important step towards the perfection of the dynamo machine occurred in 1873, when Von Hefner Alteneck, of the firm of Siemens & Halske, of Berlin, brought out* an improved form of the earlier Siemens shuttle armature. This consisted essentially in making the core in the form of an iron cylinder, and over-winding every portion of it, longitudinally, with equally spaced coils of insulated wire, several layers deep. The windings passed clear across the ends of the cylinder, and were not threaded through it. In this respect, it will be observed, there was an important difference between Alteneck's armature and that of Pacinotti or Gramme. The cylinder was mounted to rotate with a horizontal shaft, passed longitudinally through it. In another form of the armature the iron core was stationary and the wire envelope, attached to a German silver envelope, was caused to revolve over it. The advantage of this arrangement was found not to be of sufficient importance, while it necessitated a more costly structure, and such armatures have latterly been constructed to revolve bodily. The armature was mounted to rotate between the poles of a large, flat, double electro-magnet. The introduction of the Siemens machine was at once seen to mark an important forward step in dynamo design, and led to the electric light being furnished to several British lighthouses.

*Further Improvements in the Dynamo.*—Several inventors about this date endeavoured to design dynamos yielding a non-fluctuating or unbroken current. One of the most remarkable of these was the device of Lontin, who constructed several machines with armatures in the form of spokes radiating from a central drum.† Brush, in 1878, re-invented the Pacinotti armature ‡ with this difference that the projections or "teeth" (now generally known as "Pacinotti projections") were upon either face of the ring instead of upon its periphery. The ring was also placed in a vertical plane, upon a horizontal shaft, and revolved in a very intense magnetic field, obtained from two double electro-magnets. The armature of Brush's dynamo had its coils so connected to a peculiar form of commutator that those that were for the moment inactive (*i.e.* out of the magnetic field) were cut out of the circuit, so reducing the total resistance and increasing the force of the current. This "open coil" method of winding was employed by others with equally good results. Brush is also generally accredited with the invention of that important method of exciting the field magnets for purposes of automatic regulation, known as "compound winding." This consisted of a combination of the series and shunt methods, and enabled the machine to instantly modify its current to suit the requirements of the external portion of the circuit. For example, if a Brush machine were feeding twenty lamps, and ten of these were to be suddenly extinguished, the current evolved at the dynamo would instantly fall the required 50 per cent., or become again powerful if the lamps were re-lighted. This principle, and that of open coil winding, will be found more fully explained in subsequent pages.

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* Specifications of patents, 2,006 of 1873, and 3,134 of 1878.

† See Specification of patent, 473 of 1875, 386 and 3,264 of 1876.

‡ Specification of patent, 2,003 of 1878.

*The Return to Alternating Currents.*—The introduction of the Edison and the Swan incandescent lamps, about the year 1880, led to a test of the comparative merits of continuous *v.* alternating currents for such lamps. In the result, inventors of dynamos arrived at the conclusion (which has been amply justified by subsequent experience) that alternating currents were quite as suitable for this purpose as continuous currents, provided the pulsations of alternations (now known as the "phase" were of a quickly recurring character (now called the "periodicity").

*Sir William Thomson*, in 1881* suggested the employment for incandescent lighting of a machine having a disc-like armature, furnished with numerous coils near its periphery. This armature was set upon a horizontal shaft, in a vertical plane, and revolved between two opposite rings of magnetic poles. The currents which had a high periodicity were alternating in direction, and were taken direct from the machine, without being commuted. As it is obvious that such a machine cannot excite its own field magnets (for which purpose continuous current is required), a small independent dynamo is reserved for this duty alone, so that all the current evolved by the machine is available for external purposes.

*Mr. Gordon*† brought this class of machine, by independent invention, to a high state of perfection, and Mr. Ferranti, in conjunction with Sir William Thomson,‡ developed the method of winding with copper strap, producing a machine having extraordinary powers in small space. The Ferranti machine of this type has no iron in the armature, a circumstance that tends to maintain it in a cool condition, even when evolving the greatest currents. Some of the largest dynamos in existence have been erected after this model at the London Electric Supply Company's Station at Deptford. Engravings from photographs of these are given in a subsequent chapter.

Various improvements in construction were made about this period (1880–1883), by Lord Elphinstone and Mr. Vincent, by Mordey§ (improvements in ring armatures); and also by Gülcher and Gramme, while Dr. Hopkinson proved that in ordinary dynamos (his experiments related to Edison's machine), a great advantage is gained by making the field magnetic (iron) circuit as short as possible.[*] In 1886,[†] Drs. J. and E. Hopkinson elaborated an electrical method of testing dynamos, which has been productive of most valuable results as leading to a clear understanding of the interactions of these machines when worked in conjunction with electromotors.

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* Specification of patent, 5,668 of 1881.

† Specification of patent, 5,536 of 1881; and 2,871 of 1882.

‡ See Specifications of patents, 3,702 of 1883, and 702 of 1887.

§ Specfication of patent, 400 of 1883.

*Development of Constant Potential Working.*—The famous mathematical researches of M. Marcel Deprez,[‡] about 1881, led him to the conclusion (which was quickly followed by verification), that if a dynamo machine, when driven at a given speed had its field magnet excited by a constant *auxiliary* exciting current, the machine would be capable of distributing currents at a constant potential. This method of compound winding was at once recognised as marking an important step in the application of dynamos to incandescent electric lighting, and other purposes. As we have before remarked, the germ of this self-regulating principle had, as far back as 1878, been very clearly published by Varley and Brush.

*Improvements in Brush's Armature.*—In 1884, was introduced a new kind of laminated armature by Brush. The ring was, as before, after the Pacinotti pattern, but built up of thin laminations, the advantage of which was such that a Brush machine, which hitherto had been used to light sixteen arc lamps only, yielded with the new armature current for twenty-five lamps.

In 1887, Mordey introduced a remarkable kind of dynamo, for alternating current working,[§] in which the field magnet revolves, and the armature remains fixed. The magnet, which exhibits an entirely new pattern, consists of two crowns of curved horns, curving towards each other, but having a thin space for the reception of the fixed armature. This iron structure is excited by a coil of insulated wire, surrounding the central portion, within the crowns. While the magnet serves the purpose of a fly wheel, the armature being fixed may be made as thin as required, without endangering its form during working.

From about the year 1880 up to the present time, a large number of American and Continental dynamos have appeared, many of them of a high order of merit. Among American machines, the spherical armature of Thomson and Houston deserves special mention. It is not only unique in design, but has proved itself one of the best of the open coil self-regulating type of machines. Edison's dynamo, especially as improved by Dr. Hopkinson in respect of the magnetic circuit, is a noteworthy instance of simplicity and directness in design. This dynamo was one of the first, if not the first, in which copper bars were substituted for insulated wire in the armature. The Weston, the Westinghouse, and many other American dynamos, have all played a prominent part in the unprecedentedly rapid rise and progress of the science of electric lighting of the past four years, and therefore scarcely yet come within the category of historical machines.

In England, many dynamos of the highest order of merit, have been produced within a comparatively recent period. It would be impossible in the space allotted to this chapter, to even mention them all. But the thanks of the electrical community all over the world are due to those who like Professor Clerk Maxwell (*Proceedings of the Royal Society*, March, 1867), the brothers John and Edward Hopkinson (*Philosophical Transactions of the Royal Society*, i. 331, 1886), Mr. Mordey, Mr. Kapp (*Journal of the Society of Telegraphic Engineers*, xv. 518, 1867); Mr. Snell, Mr. Crompton, Professor S. P. Thompson, Dr. Rowland, of Baltimore, and others, have investigated the theory of the dynamo, and brought their conclusions to practical proof in the form of working machines.

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[*] Specification of patent, 973 of 1883.

[†] *Philosophical Transactions of the Royal Society*, p. 347, of 1886.

[‡] See *La Lumière Electrique*, Dec. 3, 1881, to Jan. 5, 1884.

[§] Specification of patent, 8,262 of 1887.

On the Continent, especially in France and Germany, the theoretical development of the dynamo has received much attention from profound mathematicians, among the most prominent of whom Drs. Frölich,[*] Deprez,[†] Herwig,[‡] and Rücker,[§] have evolved with considerable elaboration, the theory of dynamos of different descriptions.

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[*] *Electrotechnische Zeitschrift*, ii. 134, 170, 1881; and vi. 128, 1885.

[†] *Comptes Rendus*, xcii. 1,152, 1881; and *La Lumière Electrique*, xv. 1, 1885.

[‡] *Weid*, Ann. viii. 494, 1880.

[§] *Philosophical Magazine* (5), xix. 462, 1885.

# CHAPTER I.

## *ELEMENTS OF THE DYNAMO.*

THE evolution of the dynamo, as recorded in the preceding chapter, may possibly leave but an indefinite impression of the actual "build" of the modern machine upon the reader's mind. It is conceivable that the relation of the facts to each other may require some further treatment. And it may be further advisable to give, at the outset, a brief introduction to the nature of the parts themselves, so that they may be marshalled before the mental eye as a complete machine.

### Chief Parts of the Dynamo.

Every dynamo-electric machine consists of two main parts, and of several supplementary parts. The two chief parts are the *field magnet* and the *armature*, somewhat as we speak of a steam-engine as a combination of boiler and engine. In Fig. 12, N S and Y ("yoke-piece") depict, diagrammatically, the iron body or core of the field magnet. The poles, N S, are formed so as to embrace a considerable proportion of the armature, shown as a circle *a*. The coils intended to carry the magnetizing current are represented by *e e*. From the arrangement of these it is clear that the lirection taken by the winding is such that if N S and formed a straight bar, the coils would appear as a continuous spiral, wound in one direction. This form of magnet and position of armature is in great favour with the best dynamo builders; it is frequently spoken of as the "overtype," from the position of the armature being above the magnet.

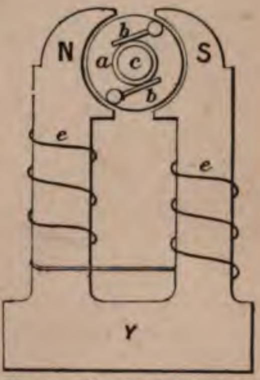

Fig. 12.—Diagram Illustrating the "Overtype" of Dynamo.

*The supplementary or minor parts* are of different kinds in different types of dynamo. In a simple machine they consist chiefly of an arrangement for *collecting* the evolved currents. The word collecting is used because most dynamos give, theoretically, not a continuous unvarying current of electricity from the armature, but a series of rapidly-recurring impulses. These are collected so as to form virtually a constant current. The arrangement for effecting this consists in most cases of two portions, first, a collecting cylinder, *c*, or "commutator," as it is frequently (but incorrectly) called, and, secondly, a pair of fixed brushes of metal, *b b*, bearing upon opposite diameters of the collector.

In other forms of the dynamo the currents given off by the armature are of an *alternating* nature. They form a series of rapidly-recurring impulses in opposite directions. These may be used for incandescent and arc lamps without change. That is, glow or arc lamps may be fed efficiently with a rapidly alternating series of electric impulses. It appears scarcely correct to call it an *alternating current*, because our conception of current consists in motion of a fluid in one direct

But the words alternating current are recognised by common usage.

In many instances the alternating current cannot be used—as in the case of electro-plating, or in the charging of accumulators. It may also be preferred to run the incandescent and arc lamps by means of a continuous current. The alternating current may easily be subjected to *commutation*, or change to a uniform direction. This is effected by an arrangement called a commutator. As in the case of a collector the commutator is furnished with a pair of collecting brushes.

In addition to these fundamental parts, many dynamos are furnished with current regulating or controlling devices, which, however, do not concern us here.

*Mechanically considered* the dynamo consists simply of a shaft, rotating in two or more bearings. From an engineering point of view, nothing in the nature of a machine could be simpler. It is only necessary to give to the shaft and the portions of the armature built upon it, the necessary stability, and to balance the whole truly. The arrangement forms, complete, a mounted armature. Its bearings are carefully proportioned so as to withstand the effects of high speed, obviating the evolution of heat, or the production of undue wear. The shaft is usually furnished with a pulley, over which a driving band from a source of power passes at the desired rate of speed.

The two chief parts of the machine consist, therefore, of a fixed part, usually the field magnet, and of a rotating part, usually the armature. In several machines these take reverse positions, and the field magnet revolves, while the armature remains a fixture.

This arrangement, however, is the exception. What is required, in relation to the two parts, is *motion in respect to each other.*

*The simplest conception of a dynamo is a conductor forced through a magnetic field.* A current of electricity flows in the conductor while it is being forced through the field. A magnetic field is that apparently empty space between the poles of a magnet. The space is, however, easily shown to be filled with something—of the essential nature of which we know nothing—which has been conceived in the light of *lines of force.* These magnetic lines, as we may call them, flow from one pole of the magnet to the other, and form a complete circuit by flowing through the whole length of the magnet.

It is the function of the field magnet to furnish this field of magnetic force. The poles—or extremities—of the magnet are for this purpose made to come close together, so as to form a nearly closed circle. Space is merely left between the poles for the free movement, without contact, of the electrical conductor. The closer together the poles, the more numerous the lines of force, or, in other words, the more intense the magnetic field. Every magnet has flowing through it and across the space between its poles, these so-called lines of force. Their number is greatly diminished by any "resisting" substance between the poles. In a narrow air space there would be many lines. In a wide air space there would be few lines, far apart. If the wide air space be filled with a mass of iron its resistance* would be greatly diminished, and a much larger number of lines would flow across the interpolar space. In order to diminish the magnetic reluctance of the armature (or field-cutting conductor) of a dynamo, iron cores are employed. In some dynamos the conductors themselves are arranged so compactly as to require but a narrow separation of the field magnet poles, and no iron is therefore required. But this consideration belongs more particularly to the function of the armature portion.

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* It is better to use Mr. Heaviside's term, magnetic *reluctance.*

*The field magnet* may, obviously, consist of a bar of steel curved so as to bring its poles to the required distance apart, and then magnetized. But these permanent-magnet dynamos, owing to the comparative weakness of the magnetic field so obtained, are not now, except in rare instances, used. A bar of equal section of soft iron, when excited or magnetized by the continuous circulation of an electrical current around it, makes a magnet of much greater power. For this reason iron magnets, excited by a current flowing in an insulated* conductor around them, are almost invariably employed in dynamos. The field magnet thus consists of an almost complete circuit of soft or cast iron, forming the *core*, and of a coil or coils of insulated wire carrying the exciting or magnetizing current around it a considerable number of times. This would form a "two-pole" dynamo. Dynamos with several magnets are called multipolar machines. Alternating-current dynamos are usually furnished with a multipolar field magnet, consisting of many magnets, arranged in two opposite circles or crowns, with opposite poles adjacent. This subject is elaborated in the succeeding chapter.

*The simplest armature* would consist, as before mentioned, of a conductor cutting its way at right angles across the magnetic lines between the poles of the field magnet. In order to obtain not only a powerful current, but currents so rapidly moving as to form a continuous flow, many conductors are used. These are so arranged in a circle as to be continually cutting their way through the field. The conductors of a *drum* armature, for instance, are arranged so as to be wound around a cylinder of soft iron, in the direction of its length. Each conductor thus usually forms an oblong loop, with an axis passing through its length. Hence, while the right hand side of the loop is passing through the field close to the N pole of the magnet, the left side is similarly passing through the field close to the S pole. In alternating dynamos the conductors usually take the form of disc-like coils, arranged in a circle upon a wheel, so that they effect a continuous cutting of the magnetic field—which, in this instance, is very narrow and intense. We can only, however, touch upon the essential nature of the armature portion here, leaving to Chapter VII. on Armatures, a fuller consideration of the various forms it assumes in practice.

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* Insulated Conductor.—This may be regarded as a copper wire wound ith a continuous covering of cotton or silk thread, so as to "confine" the urrent to the wire.

*The collector, or commutator*, forming the third portion of the machine assumes, amongst others, three distinct forms. That form applied to alternating current dynamos is the simplest. Since the armature revolves, its currents can only be passed into the useful portion of the circuit by some kind of *rubbing* connection. Two copper or brass rings are attached to, but insulated from, the revolving axis or shaft. The extremities of the armature coils are attached to these. A fixed metallic brush or spring is then arranged to touch each ring. These brushes are insulated, and form the terminals of the machine. To them the ends of the circuit leading through the lamps or other work are attached. The electrical or metallic path is thus kept up, or open between the revolving conductors and the fixed leading wires.

Drum armatures are furnished with another form of collector or commutator. Each complete loop of the conductor may be considered as requiring two terminal connections. Since there are a large number of loops, there must be a considerable number of connections, upon which the brushes may bear. It is found most convenient to arrange these *touch bars*, as we may regard them, in a circle, so that they assume the form of a cylinder, each bar being of the required V-form to attain that object, as depicted in Fig. 13. Each bar is not only to be insulated from the axis or shaft, but from every other bar. This is effected by interposing a non-metallic sleeve between the shaft and the bars, and by placing a layer of some non-conductor, as mica, between each pair of bars. The brushes are so placed as to receive the electrical impulse from each loop at the proper period of its revolution through the field. The arrangement is shown in Fig. 14.

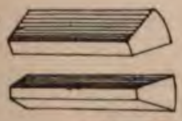

Fig. 13.—Section of the Collector Bars.

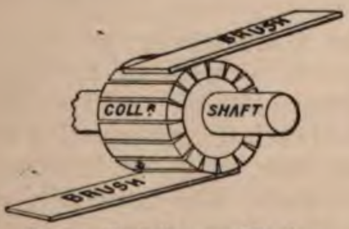

Fig. 14.—The Collector and Brushes.

The third form assumed by the collector is more properly a commutator of current. The simplest kind of commutator is that consisting of a metallic tube or ring split into two halves. These are insulated from each other, and from the shaft as before. To each half-ring an extremity of the single loop armature is attached. If two brushes press upon these half-rings, at opposite sides, the position of the former may be so arranged that while the current in the loop becomes reversed—as it does at each revolution—the rings also change to opposite brushes; so that a constant direction is imparted to the current, that is, although it is of an alternating nature with respect to the armature, it maintains a uniform direction in respect to the external portion of the circuit. The arrangement is depicted in Fig. 15. If there are several armature loops working under similar conditions, there may be several segmental pieces of the commutator. In one form of dynamo, giving alternating currents from the armature, there are but two extremities to the whole circle of coils. Since, however, there are several changes of direction of current or alternations on each revolution, there must be several contact pieces in the commutator. The latter, therefore, consists of a cylinder with the required number of insulated sections. Each alternate section is connected to one extremity of the armature wire, and the interposing set to the other extremity. We can only touch, however, upon this arrangement here, leaving to Chapter VII. a fuller consideration of the construction of commutators.

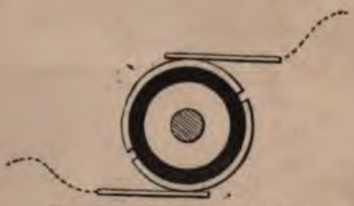

Fig. 15.—Two-part Commutator.

The complete dynamo, as shown in Fig. 16, which

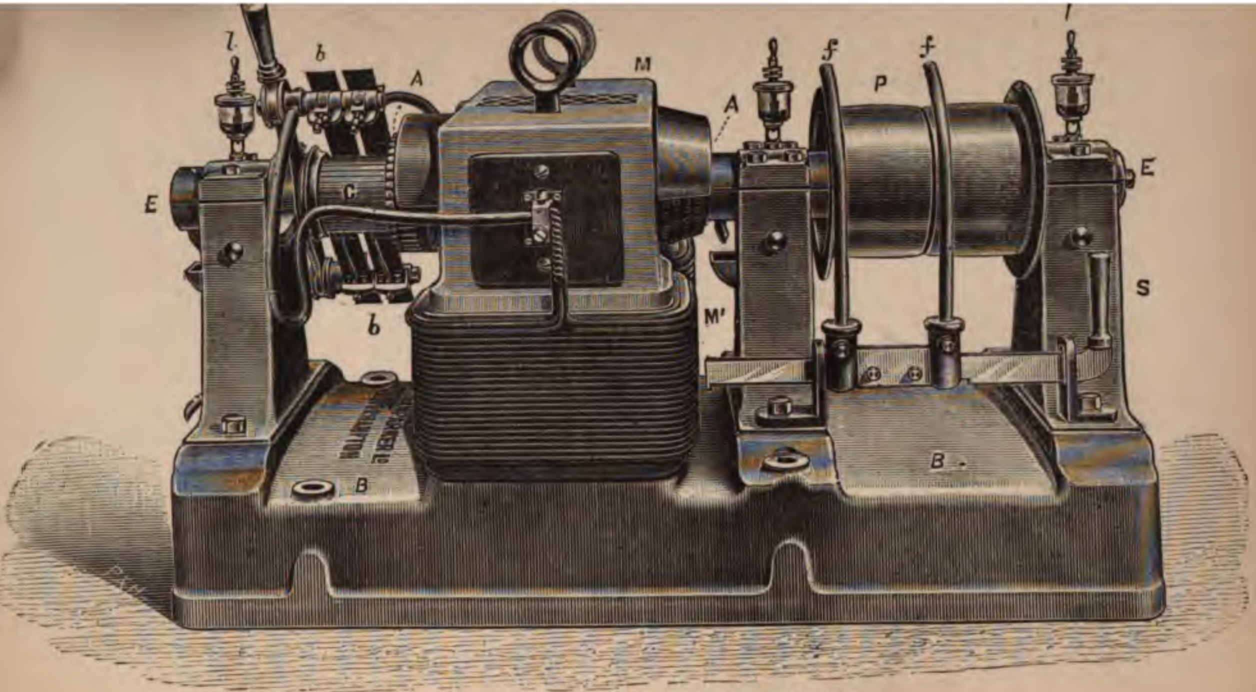

Fig. 16.—Overtype of Dynamo, depicting the Leading Features.

represents a two-pole continuous-current Lowrie Parker machine of the improved "overtype," consists of a large field magnet, M, bolted to a large cast-iron base, and excited by current in coils M′, of a drum armature, A, mounted or built upon a shaft, revolving between the poles of the field magnet, of a collector, *c*, and brushes, *b b*, and of bearings, E E, bolted to the base, on which the shaft revolves. The shaft carries the usual belt pulley, P. This particular type of machine is furnished with a third bearing, in order to better accommodate a loose pulley as well as the ordinary fast pulley. It is also fitted with a "belt striking" gear or band fork, under control of the lever, S, which enables the attendant to put the armature into motion or to stop it without reference to the engine.

## CHAPTER II.

## *NOTES CONCERNING THE ELEMENTARY PRINCIPLES.*

WITHOUT detailing the complete electro-magnetic theory applicable to the conditions of a dynamo-electric machine — a theory very fully elaborated in several text-books—it will serve our purpose here to refer to the fundamental facts upon which it is based, leaving to future chapters the gradual unfolding of the dynamo-builder's application of those principles.

### Magnetic Field.

An air-space, filled with lines of magnetic force, is called a magnetic field. A magnetic field cannot exist without an inducing magnet or current of electricity. The space surrounding and in front of the poles forms the field. As is well known, lines of attraction radiate from every part of the pole. These are most numerous in front of the pole, although they spread out in all directions. That part of the field in which the lines are most numerous attracts a piece of iron most strongly, and is said to be the most intense part. The greater the number of lines of force in a given space the stronger or more intense the field. If the magnet be bent, so as to bring its poles close ogether, the lines of force can be shown to have become *concentrated.* They are no longer diffused and scattered. Their area is restricted, and the field is said to be *intensified because the lines are crowded together.* Hence, the strongest field is that in which there is the greatest number of magnetic lines per square centimetre, or square inch, as the case may be.

The magnet setting up the field may consist of a bar or a horseshoe of hard steel. This is the only substance yet found capable of *retaining* a considerable proportion of the magnetism conferred upon its molecules.* Or the magnet may consist of a bar or a horseshoe of soft iron, around which an electric current is caused to circulate. The former type is called a "permanent" magnet because it retains (for a considerable time if of tungsten steel) the polarised condition, although no magnet is truly permanent. The latter case represents an electro-magnet—a coil of insulated wire surrounding a soft iron core—but its polarised or magnetic condition rapidly decreases after the stoppage of the current.

*Magnetic Field due to a Current-bearing Wire.*—But magnetic lines can also be set up by a current-bearing helix of insulated wire. And it is well known that such a helix behaves, in many respects, like a magnetized bar of steel or iron. But the magnetic field in a dynamo invariably proceeds from a field-magnet, usually of soft iron, excited to a high degree by a powerful current.

*Curves of the Magnetic Lines.*—If we repeat the well known experiment of placing a sheet of paper near to the pole of a strong magnet, and dusting iron filings thereon, the particles will arrange themselves, under slight agitation, in the well-observed diagram, showing tufted lines of attraction.*

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* An interesting fact has recently been brought to light with reference to steel, that an admixture of as small a proportion of manganese as twelve per cent. will render steel almost indifferent to magnetism; it cannot be magnetized or attracted by a magnet.

*Diffusion of the Lines.*—If we endeavour to *diffuse* the lines by surrounding the pole with an iron ring considerably wider than the pole, our diagram will present an entirely different appearance. The inductive effect of the distant iron circle causes considerable diffusion of the lines.

*Concentration of the Lines.*—If, on the other hand, we remove the ring, and substitute the conical extremity of an iron rod, held near to the paper, in front of the pole, the diagram will exhibit marked concentration.

*Magnetic "Leakage."*—In the former case the evil effects of adjacent masses of iron, causing, as they do, loss of magnetic lines by diffusive *leakage*, is evident. In the latter case the beneficial effect of so arranging the armature part that it tends to centre the lines upon itself is very marked.

*Physical Significance of the Lines of Force.*—The accurate predetermination of the performance of a dynamo can only be effected by working under a clear conception of the real nature of the magnetic circuit. The latest and most fruitful theory of the dynamo takes the magnetic circuit as its starting point. The magnetic lines, as is well known, tend to move or exist in a circuit. In the case of a dynamo, the magnet may be regarded as a core in the form of a ring, with a gap in it for the purpose of receiving the armature. Now the magnetic lines induced in the core *tend to complete the circle.* They would be at a maximum if the bar formed a complete circle.

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* Students investigating this subject will find that paper that has been dipped in liquid paraffin wax (called paraffined paper), will enable them to fix these magnetic diagrams, by carefully placing the paper upon a hot surface, or otherwise liquefying the wax.

*Magnetic "Reluctance."*—The air gap, however, presents very considerable magnetic resistance.* But it can be clearly shown that the circuit is completed through it—that is, a certain number of lines cross the gap. If we insert in the gap a piece of soft iron the reluctance of the gap will be reduced, and the field will be considerably intensified; that is to say, a greater number of lines will be able to force their way across the reduced space. This is due to the fact that iron presents much less magnetic reluctance than air.

This gap, then, is the region of particular interest in every dynamo. Any conductor cutting the lines of force will have induced in it an electromotive force tending to set up a current. The more intense the field—the greater the number of lines cut—the stronger the electromotive force induced in the conductor.

Leaving our conception of the magnetic circuit for a time, it will be well to go back and inquire what is meant by *lines of force.* When a field is commonly said to contain 16,000 lines to the square centimetre, the line must have, by general consent, been invested with some physical significance.

*A Magnetic Unit,* or line of force, may be more practically defined as the amount of magnetism induced in an area of one square centimetre, at the centre of a coil (having a diameter of 10 centimetres), forming a single turn, and carrying a current of 7·9578 ampères. This expression relates to the magnetic field always found surrounding, and in the neighbourhood of a current, without reference to iron.

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* In order to avoid confusion with electrical resistance Mr. Heaviside has proposed the apt term *magnetic reluctance*, for the resistance persented by an air gap, or that due to any body not readily *permeated* by the magnetic lines, or the specific magnetic resistance of the iron core itself.

The *intensity* of the magnetic field is expressed in terms of the number of lines of force per square inch or centimetre. The *quantity* of magnetism is measured by ascertaining the total number of lines of force.

*The Value of the Lines of Force* is determined in terms of the *dyne* (derived from the system of centimetre, gramme, and seconds units), the generally accepted unit of magnetic force. A field is said to exert an attraction or repulsion of so many dynes in a certain area. It is possible, then, to determine, by means of this unit, in its relationship to the electrical units, the total strength of the field—the total number of lines the armature conductors will cut in their rotation. It is further possible, when the number of lines is known, to determine the current that will be evolved in the armature at a given speed. But we can ascertain the strength of the field in terms of the magnetizing current. If we know the magnetic "conductivity" of the iron core of the field magnet it will be possible to say how strong a magnetizing current will give a certain number of lines of force in the field.

The problem of predetermining the output of a dynamo, as yet, perhaps, only sketched on paper, is thus not only within our power, but that within limits so narrow that the calculated and actual outputs shall not disagree more than one or two per cent.

*Lines of Force and a Conductor.*—Knowing the number of lines in the field, and the rate of motion of the armature conductor across it, it would be an easy matter to arrive at the induced electromotive force, if we calculate upon the generally accepted dictum that "*a conductor, cutting lines of force at the rate of*

100,000,000 *per second, will have induced in it an electromotive force of one volt.*"

*Lines of Force in the Field of a Dynamo.*—Dr. Fleming estimates the lines of force in the fields of the best dynamos at from 6,000 to 10,000 per square centimetre. A definite value must be found for the maximum magnetization of iron; that is, the number of lines that can be forced through it per square centimetre, with a given magnetizing current, must be ascertained. Ever since the investigation by Dr. Rowland of the laws of the magnetic circuit attempts have been made to settle this question. The nature of the iron bears so strongly upon the conditions, however, that it appeared, for a long period, almost hopeless to arrive at a definite basis for a workable theory. Later researches bearing upon the permeability (magnetic conductivity) of the iron have, however, proved so fruitful that, knowing the nature of the iron, it is possible to predict the number of lines that would result from a magnetizing current of so many ampères in the exciting coils.

*Maximum Magnetization.*—From numerous experiments it would appear that the maximum number of lines of force which usually traverses a bar of soft, annealed iron one square centimetre in cross-section, is about 32,000. In some of Prof. Ewing's experiments, however, a magnetization, under extraordinary conditions, as high as 45,350, was attained. But beyond a certain limit the magnetizing current has to be so relatively enormous that in dynamos even the maximum here stated is almost unknown. There is, probably, however, no theoretical limit to the magnetizability of soft iron. For further information on this subject, as it affects field magnets and armatures, the reader is referred to pp. 54—56, to Dr. J. Hopkinson's researches,* to Prof. Ewing's experiments, † to an able paper on *The Magnetization of Iron*, by Shelford Bidwell, F.R.S., ‡ to Prof. Rowland's researches, § and to Prof. Thompson's recent lectures before the Society of Arts.

### Motion of a Conductor in the Field.

The next step towards the conception of a dynamo is to suppose an armature in its simplest form. If a loop or a coil of wire, forming a closed circuit, be set in motion in a plane at right angles to the lines of force, so as to cut across them, there will be induced in it an electromotive force. All dynamo machines are based upon this principle. The direction of the current will depend upon the direction of motion of the conductor, and also upon whether it is approaching the pole or withdrawing from it. The amount of the electromotive force will depend upon the intensity of the field, the velocity of the conductor, and upon the number of turns the latter takes when in the form of a coil.

*The Magnetic Field of a Dynamo* almost invariably occurs between two poles of the same magnet, brought close together, leaving space sufficient for the conductor or coil to rotate therein.

*The Armature* is the name given to the conductor or coil which is caused to rotate in the field. It may or may not contain a core of soft iron. It may consist of from one to any number of turns of insulated wire. It is always intended to cut the lines of force in the field as close as possible to the poles of the magnet.

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* *Phil. Trans. of the Royal Society*, Part II., 1885.
† "*Industries*" for Sept. 30, 1887.
‡ *Phil. Trans.*
§ *Electrical Review*, xv., p. 368, 1884.

*The Commutator* is merely a device, moving with the axis, for commuting the currents induced in the coil to a uniform direction. In many dynamos a commutator is not required. The currents are used, for practical purposes, in a constantly alternating condition.

We are now, as it were, in a position to form a summary of the essential conditions of dynamo machine working.

(*a*) Currents are induced in conductors by moving them near to magnets, or moving magnets near to them.

(*b*) To move the conductors near to magnets, or *vice versa*, calls for a mechanical effort. If the circuit of the conductor be open no current will result, and the resistance to motion will be that due to the weight, &c., of the conductor.* If the circuit be closed a current will be evolved, which calls for an additional expenditure of energy. This additional energy may be said to be returned to us in the form of electricity. It at once shows the principle of the dynamo—a conversion of mechanical into electrical power.

(*c*) The direction of the currents depends upon the direction of motion. An advancing conductor and a withdrawing conductor will exhibit oppositely moving currents.

(*d*) The most rapid motion produces the most powerful electromotive force or current, and *vice versa*.

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* For other reasons this does not, however, strictly apply to the case of alternating-current dynamos.

(*e*) The most powerful magnetic field induces the most powerful electromotive force, and *vice versa*. If the field be double, so as to influence both halves of the conducting coil at once, the effect will be doubled.

(*f*) The longer the conductor—folded up in the form of a coil—the stronger the current evolved; this has the effect, simply, of increasing the *number of turns* of the wire.

(*g*) Either a permanent (steel) magnet, or a soft iron electro magnet, may be used to form the requisite magnetic field, and in the latter case the current used to generate the field may be either an independent current or part of the current evolved by the machine itself.

(*h*) The ever-changing *impulses* of a single coil revolving in the field cannot be changed to a continuous current, but they may easily be given a uniform direction by commutation.

(*i*) Continuous currents are obtained when some part of the conductor is always moving across the most intense region of the field. This is usually accomplished by distributing a long conductor over the surface of a uniform shaped body, as a sphere or a cylinder.

To design a dynamo upon the above lines the chief conditions to aim at would be the following:—

(1) To produce the strongest possible magnetic field by means of an electro magnet.

(2) To cause to rotate between its poles, at the greatest possible speed, an armature composed of the greatest possible number of turns or convolutions; and this conductor to be of the thickest possible wire.

The magnetic field should be the strongest possible, because the most intense field contains the greatest number of lines of force. And the electromotive force generated by the dynamo depends greatly upon the number of lines cut by the armature in its revolution.

The armature should consist of the greatest possible number of convolutions (length of conductor), because the greatest length cutting the field produces the greatest electromotive force. And (with special reference to strength of current) the wire used should be the thickest possible, so as to reduce the electrical resistance of the armature to a minimum.

No dynamo yet built can be said to realise these conditions. It is obviously impossible to embody them all in one machine. It is quite clear, for example, that the greatest possible length and the greatest thickness of the armature conductor in the smallest possible space are conditions impossible of realisation.

Again, the magnetic field, since it must be confined within a limited area, will only admit an armature of certain dimensions. The magnetic lines of force are restricted, as to the greatest number, to a space close to the poles, and one conductor must cut this space across the most advantageous region.

From these considerations it appears that to design the best possible dynamo involves much more than a mere attempt to embody, in one structure, the best possible conditions, according to the purely physical theory of machines of this class.

To produce the most intense magnetic field possible in the smallest space involves a careful study of the nature of the magnetic circuit, as well as sound views of the utilisation of current in exciting this field, so that no line of force, or no part of the current, is dissipated uselessly as heat in the machine.

To devise an armature in which the greatest length of conductor is combined with the least possible resistance is in itself no easy problem. Many conditions have to be provided for, as well as these primary lines of guidance. The wire must, for example, be disposed in a symmetrical fashion. It must be so condensed as to come well within the inductive influence (as close as possible to the poles) of the field. If we regard the resistance of the wire—a very important item in itself—the wire must be thick, and this is incompatible with both length and concentration. Finally, speed of rotation is limited by mechanical drawbacks sufficiently great to confine velocity within certain limits.

# CHAPTER III.

## *DYNAMO FIELD MAGNETS.*

A DYNAMO is a machine for converting power into electricity. It effects this by virtue of a condition or effect called induction. The action of the dynamo as such has no connection with "*friction.*" The first notion of the uninitiated is to connect the swiftly-revolving portion with friction. The rotating armature, on the contrary, moves round in a perfectly clear air space. But this clear air space, containing nothing visible, is, nevertheless, filled with the most intense lines of force. The space is, therefore, not empty in an electro-magnetic sense. It is the function of the field magnet to maintain this powerful stream of lines of force.

Any metallic body entering this apparently clear air space will be immediately subjected to the inductive influence. If it be of iron it will become a powerful magnet. If it be of copper it will, when in motion perpendicular to the magnetic lines, be raised to a high electrical potential, or be filled with a current of electricity. If it be of copper enveloping a core of iron it will become a common form of *armature.* Such a combination can be very easily rotated in the lines of force—provided that the conductor be severed so that currents cannot *circulate* therein. But if th urrents be collected and flow in a circuit, the armaure becomes a resisting body, requiring considerable orsion to move it in the apparently empty chamber. The power exerted in turning is the expended energy. The current of electricity is the energy of conversion. If the dynamo be built upon certain lines the proportion of the energy *returned* by it as electricity may be as high as ninety-five per cent. of that expended. If the machine be constructed upon bad principles, only a small proportion may be so recovered.

The dynamo consists, thus, of two chief parts, a fixed part known as the field magnet,* and a revolving part termed the armature.

The field magnet may, if desired, be a common horseshoe of hard steel. Such an arrangement can be strongly magnetized once for all, forming, in fact, a "permanent" magnet. A machine built in this way would be generally known as a magneto machine.

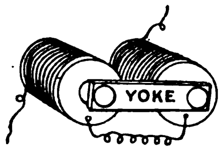

Fig. 17.—Electro-Magnet of the Common Type.

But there is one great advantage in employing a temporary soft iron magnet instead. It can be made enormously more powerful. If it is more powerful it can impel many more lines of force through the armature. As the inductive effect is proportional to the number of lines of force in the field, it follows that such a machine will yield, weight for weight, much more electricity than a "magneto" machine mentioned above. Obviously, the dynamo machine will call for a correspondingly great expenditure of engine power in driving it. A small percentage of this expended energy will be absorbed in maintaining the electro magnet in its highly excited condition.

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* Although an electro-magnet may be said to be simply a bar of soft iron, furnished with a current-bearing insulated wire coiled many time around it, this is not its usual form. In most cases it is requisite, in orde to concentrate the field, to bring the polar extremities of the iron core clos together; this may be, and is frequently, effected by simply bending tl bar to form a U, but as this method is impracticable in dealing with lar bars, and indeed generally unnecessary; it is simpler to divide the bar a join the two limbs by means of a well-fitted yoke piece, as in Fig.

But the substitution of an electro magnet for a permanent magnet offers other advantages. The electro magnet consists, as understood, of a suitably shaped horseshoe of iron. To render it magnetic there is coiled upon its two limbs a considerable length of insulated wire. An electrical current flowing in this wire imparts, *by induction*, magnetism to the iron. In other words, it is supposed to throw the molecules of the iron into a peculiar arrangement known as "polarization." The magnet is thus more or less magnetic. The magnetism rapidly ebbs away if the electrical current be stopped. The amount of magnetic excitement, the intensity of the magnetic field, the number of lines of force, will depend upon two things (1) the number of turns the conductor takes around the iron; (2) the strength of the electrical current. But we may consider at once that the intensity of the field is proportional to the strength of the current. We are now in a position to see clearly that the current yielded by such a dynamo can be very easily *regulated* and *controlled* by merely varying the strength of the current flowing around the magnet. In shunt and other dynamos this is very generally done by

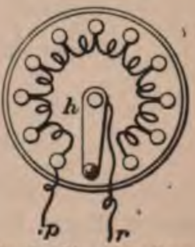

Fig. 18.—Rheostat or Regulator of Resistance.

hand, simply throwing in or withdrawing certain lengths of *resisting* wire to or from the field magnet portion of the circuit. Fig. 18 represents a resistance regulator arrangement, consisting of a series of coils connected as shown to a number of contact studs arranged in a circle. If the end of the field magnet circuit connects to $p$, and the wire $r$ be consequently regarded as its extremity, the circuit will remain practically as it was when the lever $h$ is brought to the first stud to the left. If it be moved to the second stud the current will have to pass through the resistance of one coil, and so on, until, when the lever reaches the last stud all the coils will be in circuit.

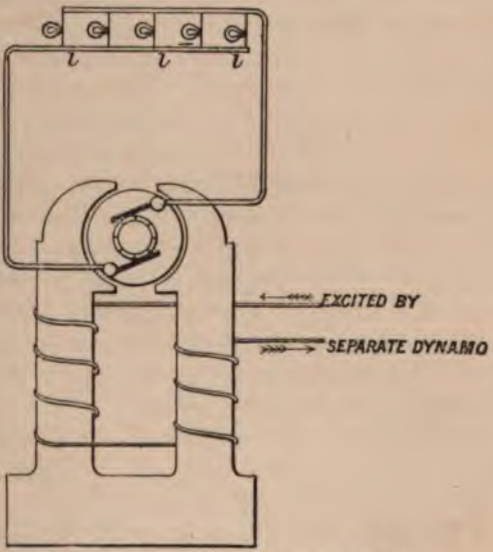

Fig. 19.—Diagram showing separate Excitation.

*Separate Excitation.*—Since a dynamo may be a machine in which the magnet is excited by an independent current—that is, a current furnished by another dynamo (Fig. 19)—it is well to remember that such a machine may be perfectly controlled without any interference with the current it is yielding from its armature. But this method of "separate excitation" is more the exception than the rule in the case of dynamos of moderate dimensions.

Again, since an ordinary dynamo *itself* supplies the current for exciting the field magnet, it is clear that this circumstance may put it in our power to make the issuing current regulate or control itself—in short, render the machine both self-exciting and self-regulating.

The automatic regulation may be effected by several different methods, and they almost invariably refer to the exciting coils of the field magnet. Let us, therefore, briefly consider the leading methods of winding the magnet, leaving to Chap. XII. a fuller development of the question of governing dynamos.

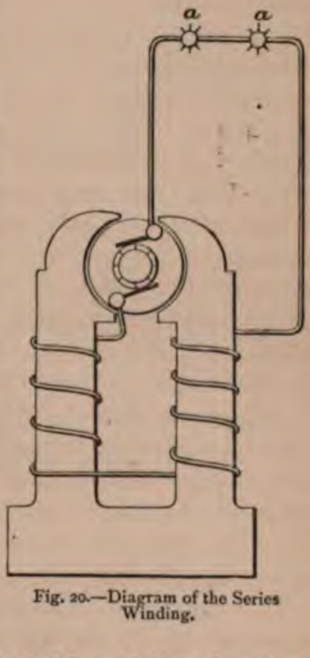

Fig. 20.—Diagram of the Series Winding.

*Series Winding* was really well known before any attempt was made to render dynamos self-regulating. In a series dynamo the current evolved by the armature passes direct to the field magnet coils, and through them to the external portion of the circuit—lamps or other work in circuit, Fig. 20. In this place we are not immediately concerned in the question of appropriate gauges of wires and so on, but it may be useful to observe that the magnet coils must, or rather may, be of very thick wire, otherwise its electrical resistance would greatly weaken the current. It calls for little consideration to discover that such a dynamo would be liable to serious fluctuations in its output unless the lamps, &c., in circuit called for a constant current. Suppose such a dynamo to be feeding five arc lamps. All might go well until an additional batch of lamps was switched into action on the same circuit. If five more lamps were to be put in the circuit, the current evolved would fall greatly in strength by reason of the extra work (or resistance) switched in. This fall in the current would at once weaken the field magnet. The output of the machine would thus fall off, and instead of an increased output of electromotive force we would have a diminution. Judging from this simple example, a dynamo wound for series working is scarcely adapted for working in a circuit when the demand is apt to vary. Leaving the question of series winding for a time, however, let us see how this fault has been partially obviated by arranging the magnet coils as

*Shunt Winding.*—Without detailing the methods of shunt winding, we may briefly consider the effect of this arrangement as it affects the field magnet. If two paths be open to an electric current it chooses neither entirely. By a well known law it divides itself between them. The greater portion passes away by the path that offers least resistance to its "flow"; the lesser portion by the path offering the greater resistance. A shunt-wound dynamo (Fig. 21) is a good example of this. As the current leaves the armature it finds two paths open through which to complete the circuit. The path of least resistance—let us suppose it to be the thicker and shorter wire of the two—is the external "work"—lamps, &c. The path of greater resistance—in reality the longer and thinner wire—consists of the coils surrounding the field magnet. In the working of this dynamo the "field" is maintained by a *small proportion* of the current only, not by the entire current. The magnet is therefore wound with a great length of fine wire, offering relatively a great resistance. The coils thus form a by-path or shunt, through which the proportion required passes by the law of divided resistances.

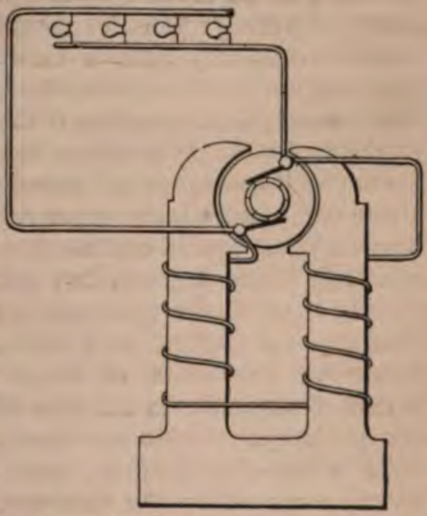
Fig. 21.—Diagram showing the Shunt Winding.

Suppose such a machine feeding a circuit of five arc lamps, and that it is working *under* its full power. If five more lamps be added the resistance in circuit will be nearly doubled, much more work must be done by the machine to maintain the additional lamps. ct of switching in additional resistance upsets the balance between external circuit and field magnet coils. A *smaller proportion* of the current will pass momentarily in the external circuit and a *larger* proportion in the magnet coils. The result of this will obviously be an *increase* in the power of the magnet, which, re-acting upon the armature, will cause it to evolve a relatively greater current. In an instant the machine has thus almost doubled its output. The converse of this takes place if the work in circuit be diminished. If all the lamps but one be switched off, the external resistance will thereby be greatly reduced. There will occur a momentary relatively great rush of current by that path, and the field magnet will receive relatively little or none, but this instantly weakens the field, which in turn cuts off the supply at the armature—as it were—and the balance is once more restored. The effect of shunt winding, however, is more remarkable in the case of maintaining incandescent lamps. These are usually placed across two main wires—the leading wire and the return in multiple arc—from the machine, and not in simple series circuit as in the former case. The effect of switching in a double number of these lamps would therefore be to *diminish slightly* the external resistance, since five additional paths would be open to this portion of the current, and the current would therefore slightly increase. At the same time the field magnet would receive a little less current, and the field would become a trifle weaker, but the effect on the whole would be to light up the additional lamps satisfactorily. In this way a shunt-wound dynamo is found to regulate itself within reasonable limits, and even within wide limits if the resistance of the armature be relatively small. But it is not perfect except for certain classes of work. A relatively perfect method of self-governing, as far as it relates to the field magnet, has been sought in a *combination* of the two foregoing methods, series and shunt. This is now generally called *compound winding*,* and we may briefly enquire into its nature, inasmuch as it affects the magnetic field. Very early in the history of the dynamo Mr. Varley suggested and Mr. Brush employed this method. The first use to which it was put in the Brush machine would appear to have had distinct reference to self-regulation, or to enable the dynamo to supply a very small current without risk of having its magnetic polarity reversed by secondary currents from an electro-plating bath.

Two methods of compounding by differential windings of the field magnet are in common use. But whatever particular method of compounding be employed, its aim is always towards making the dynamo regulate towards constant potential or electromotive force. In arc lamp lighting, where most of the work is in series on one circuit, constant *current* is essential, and the potential may vary somewhat without greatly influencing the lamps. But in the case of incandescent lighting, with lamps placed across the wires in multiple arc, the case is far different. Any variation of *potential* will tell immensely upon the brightness of the light. A five per cent. rise or fall would be quite impracticable. It is for this latter purpose that compound windings prove most useful. The combination renders the maintenance of the potential, within wide limits, a comparatively simple matter. For the latter purpose the windings generally consist of only a few coils of the main circuit, arranged precisely as in series winding. Superimposed upon the series coils are the shunt coils, consisting of a relatively large number of convolutions of fine wire. The extremities of the shunt winding are simply connected to the commutator brushes, Fig. 22. The current thus has two paths open to it. As it leaves the armature the greater part of it will enter and pass through the thick series coils, and so through the external portion of the circuit. But a small proportion will flow through the finer and longer shunt coils. Since the resistance of the latter is great compared with that of the armature, any variations in the current will scarcely alter the magnetizing power of the shunt. The latter, therefore, may be regarded as affording an almost uniform excitation of the field.

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* A term first suggested, we believe, by Messrs. Crompton and Kapp, and now in general use.

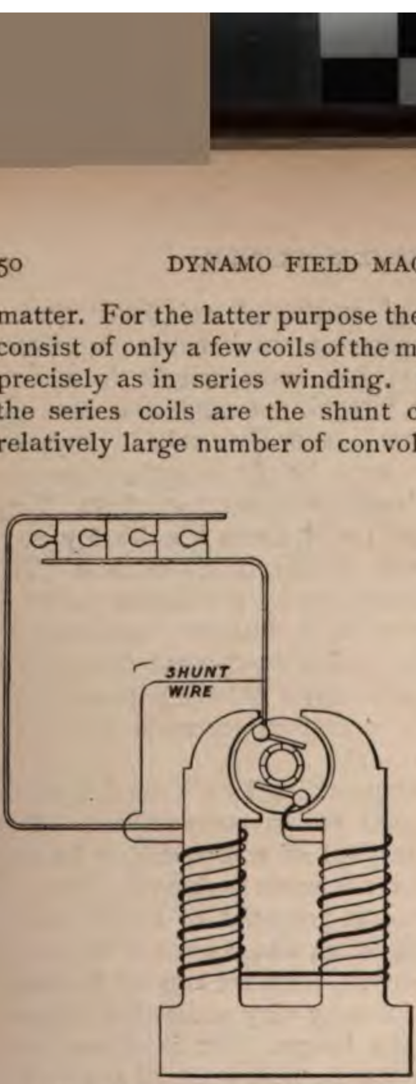

Fig. 22.—Diagram of Compound Winding.

Let us now consider the use of the series windings. our consideration of the effect of running a simple shunt-wound dynamo to feed incandescent lamps (p. 48), it appeared that upon doubling the number of lamps an increased *current* was called for, which we have seen would be promptly supplied. But at the same time there would occur a slight fall of the electromotive force (due to the increased current), and we have seen that the machine would not readily supply this increased potential. Hence, in our supposed case, the addition of more lamps would undoubtedly abstract from the normal brilliancy of the light evolved. If, however, a few turns of the main circuit be taken around the magnet, in addition to the shunt coils, we have a dynamo mostly shunt but partly series, and the obvious effect of the above supposed increased current will not be to pull down the potential, but to maintain it at full value, because this augmented current, passing as it does around the field magnet, will correspondingly increase its power.

It will be observed that in this supposed instance the "compensating" coils (series) must not have too powerful an effect, otherwise the over-compensation would raise the potential above the normal and destroy the whole of the lamps.

Another variety of the compound method in common use may be mentioned. It is chiefly employed for such purposes as electro-plating, where the *current* required is apt to vary to a considerable extent, and it is requisite to maintain the potential constant. This method merely consists in furnishing an ordinary series dynamo with a few coils of shunt winding, the wire being much finer than that of the series coils. Its object is to maintain the magnetism as nearly constant as possible, independent of variations in the current. Mr. Brush's first attempts to regulate dynamo in this way were so successful that when the current varied from one to some hundred ampères the potential scarcely varied one volt. When first applied to a dynamo,* it consisted of a length of fine wire wound upon the core, under the series winding, and was called a "teazer."

Several modifications and combinations of the foregoing methods of exciting the field magnet are in use, but we must leave them to be dealt with in Chap. XII.

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* Brush's patent, specification 2,003, of 1878.

# CHAPTER IV.

## *CALCULATIONS RESPECTING EXCITING COILS.*

WE have already seen that the intensity of the field in a dynamo determines more than any other condition its performance. If we can calculate beforehand the exact conditions under which a given force of field can be produced, we shall be a long way towards the realisation of the design of a dynamo of any required capacity.

Dealing as we do with a mass of soft iron of not very complex shape, it would appear simple enough to arrange coils to magnetize this to any given degree, with a given current. The working conditions do not, however, fall within lines so restricted.

*The magnetizing power of a current* is proportional not only to the strength of the current (expressed in ampères), but also to the number of convolutions of the wire around the iron. If a current of one ampère flows five times around the core, its magnetizing power will be the same as that of a current of five ampères flowing once around the iron. The term *ampère-turns* is in general use to express the number of ampères multiplied by the number of turns in the exciting coil. Hence, *the magnetizing power of the current is proportional to the number of ampère-turns.* The properties of iron vary so much, however, that although the above is strictly true with respect to the current, the magneti intensity produced cannot be so accurately determined.

*The permeability*[*] *of iron to magnetism* is not constant. As the magnetic intensity rises the iron becomes less and less permeable. This fact has induced several physicists to make experiments upon iron, and to plot out certain general results, which, however, are not always strictly applicable in practice.

It would appear, from many experiments by Dr. Hopkinson,[†] and also by those published by Mr. Bidwell, F.R.S., and Dr. Rowland, that the magnetic permeability of iron (except as for a particular sample) cannot be determined once for all. Although approximate results may be arrived at, and are, as a matter of fact, arrived at by many builders of dynamos from calculation alone, the results are shown to be so generally unsatisfactory, that a more accurate method is much to be desired.

*Dr. Rowland's Researches.*—The method followed by Dr. Rowland, in his masterly investigation of this subject, is as follows:—The class of iron intended for use as a fixed magnet having been determined upon, either the magnet core itself or a sample thereof is taken. Over a convenient part of the core is wound an exciting coil.[‡] A source of current, a rheostat, or variable resistance regulator, and a reversing key, along with an ampère-meter, are put in circuit with the coil. This constitutes the exciting part of the arrangement. The induction part consists merely of a small coil slipped over another portion of the core.* In the circuit of the small coil was placed a ballistic galvanometer. A number of observations are then taken by passing gradually increasing strengths of current through the exciting coil, and while the current is still on it is suddenly reversed. The consequent swing of the galvanometer is noted. This is repeated for each increment of exciting current. The experiment proceeds until the iron is in the condition called saturated—that is, until the induction coil evinces no greater value of magnetization upon increasing the exciting current. These two sets of figures—the particular values of the exciting current, and the resulting induced currents (or *magnetic intensities*) are then utilised in the formation of a graphic diagram. The strengths of the current are plotted out horizontally, and the magnetic strengths evoked on the vertical line.

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[*] Permeability is usually symbolised by the letter $\mu$. The permeability of air and non-magnetic substances is taken as 1. Magnetizing force is usually symbolised by the letter H. The magnetization produced is symbolised by B. Prof. Thompson states that a magnetic force capable of creating in air 50 magnetic lines to the square centimetre had the power to magnetize a piece of iron with 16,062 magnetic lines per square centimetre. The practical limit of magnetization in iron of the best quality is about 20,000 lines to the square centimetre, or 125,000 to the sq. in. In *cast* iron it is but 12,000 lines per square centimetre, or 70,000 per sq. in.

[†] *Phil. Trans. of the Royal Society*, II., p. 455, 1885.

generally considered advisable to employ wire sufficiently thick rry the intended maximum current, and to construct therefrom coil having a depth equal to half the diameter of the core.

*A curve of magnetization* is thus formed, showing at a glance the magnetic permeability of the iron or magnet, and yielding the most exact information concerning the current or ampère-turns requisite to excite in it a given intensity of field. Each sample of iron on being tested will yield a similar dual line of figures, which can be employed in the formation of a fresh curve, characteristic of the nature of the iron.

For further information on this important and interesting subject, the reader is referred to the original papers. We can only mention the excellent practice observed by the best builders of dynamos in reference to these diagrams. A great deal of information is acquired by experiment upon samples of iron, and the results shown in large curves. It is noteworthy that different results are frequently obtained from observations upon different samples of the same make and quality of iron. But a practical mean is soon attained, from which approximately accurate forecasts of the dynamo's performance can be deduced.

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* As a core Prof. Rowland employed an iron ring, the exciting and induction coils occupying its opposite diameters.

*Electro-magnet Formulæ.*—The enormous mass of facts concerning the strength of electro magnets and the deductions therefrom, given in most books on electricity, are now recognised, for reasons already stated, as purely empirical. These time-honoured equations connecting the strength of the current with the degree of magnetization, have been strangely upset by dynamo machine practice within the past few years, and all that we can say we know about iron under magnetization is that it forms a substance of ever varying character, as to composition and molecular structure, and that any formula relating to it is extremely unlikely to approximate to truth. Even the latest formulæ leave much to be desired, because they usually involve *determinations of constants upon the magnet after it is constructed*, unless exhaustive experiments upon the permeability of the iron have been made beforehand.

## Modern Conception of a Magnetic Circuit.

Quite different results have been attained by the latest developments of the conception of a magnetic circuit. Dr. Rowland appears to have been the earliest investigator of the problem of magnetic circuits with a direct view to find an accurate expression for the electromotive force of the dynamo in terms of the current of magnetization. In his paper* he proposed a formula for the number of lines of force in the magnetic field. If B be the total number of lines of force, N the number of magnetizing coils, and C the current, B will be proportional to N and C, and inversely proportional to the resistance to the lines of force in the circuit. This resistance is proportional to L, the length of the iron of the system, divided by S, the cross section of the magnet, and by $\mu$, the magnetic permeability of the iron, or conductivity of iron for lines of force. Let $l$ be twice the width of the air gap between armature and pole piece, and A the area across which the lines of force flow; we have then to add another quantity, $p$, which depends upon the resistance to those lines of force which escape in all directions, and represents the loss due to that cause. Then the equation,

$$B = \frac{N\ C}{\frac{L}{S\ \mu} + \frac{l}{A + p}}.$$

Another able exposition of this problem was published by Mr. Gisbert Kapp in 1885.† For reasons stated in the paper, the unit of line of force used was 6,000 C.G.S. units (so that division by $10^6$ instead of $10^8$ might be made). Let Z stand for the number of lines of force, $n$ for revolutions of armature per minute, and N $t$ for the number of turns of wire around the armature,

$$E \text{ (volts in armature)} = Z \cdot N\, t \cdot n \cdot 10^6.$$

A formula is then given for the *magnetic circuit.* Let $P =$ the exciting power of the magnetizing current in ampère-turns; $R_a$ the magnetic resistance of the air gaps (between armature and polar faces of magnet); $R_A$ magnetic resistance of the armature core, and $R_F$ that of the field magnet. Then

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* *Electrical Review*, xv., p. 368, 1884.

† *Proc. Inst. Civil Engineers*, lxxxiii., 1885-6.

$$Z = \frac{P}{R_a + R_A + R_F}.$$

Further, let $\delta$ represent distance across the span between armature core and polar surface; $b$ breadth of armature as measured parallel to axis; $\lambda$ length of arc embraced by polar surface, so that $\lambda b$ is the polar area out of which magnetic lines issue; $a$, radial depth of armature core, so that $a b$ is area of section of armature core; A B, area of field magnet core; $l$, length of magnetic circuit within armature; L, the same in field magnet. All the dimensions are supposed to be expressed in inches or square inches respectively; then, in reference to a single magnetic circuit, the specific magnetic resistance of air being written 1440,

$$R_a = 1440 \frac{2\,\delta}{\lambda\, b},$$

$$R_A = \frac{l}{a\, b},$$

$$R_F = \frac{L}{2\ AB}.$$

The co-efficient 2 refers to the specific resistance of wrought-iron or charcoal-iron. If cast-iron magnets are used it becomes 3.

### Ohm's Law and the Magnetic Circuit.

The conditions affecting the magnetic circuit bear a striking resemblance to those controlling the ordinary al circuit. Indeed, the magnetic flux (as con- authorities have agreed to term the flow of lines of force), symbolised $M_F$, can be calculated, as we have already seen, if the magnetizing force (inducing current) and the sum of the magnetic reluctances is known. The magnetic reluctance, then, is directly proportional to the length, and inversely proportional to the cross section and permeability of the material composing the magnet core:

$$\text{Magnetic Reluctance} = \frac{L}{S\,\mu}.$$

When L = length of the magnetic circuit, S = section, $\mu$ = permeability.

In a dynamo machine the magnetic reluctance is made up of

(*a*) The field-magnet core measured from pole face to pole face.

(*b*) The armature core, provided this is of magnetizable material; if no iron is used, as in alternating dynamos, the whole armature space is to be treated as air (air and copper being regarded as equal in permeability).

(*c*) The air gaps (in the case of an iron armature core).

In the form of an equation: (*a*, field magnet; *b*, armature core; *c*, air gaps):

$$\text{Total magnetic reluctance} = \frac{L\,a}{S\,\mu} + \frac{L\,b}{S\,\mu} + \frac{2\,L\,c}{S\,\mu}.$$

As in Ohm's law:

$$\text{Number of magnetic lines} = \frac{\text{Magnetizing force}}{\text{Magnetic reluctance}}.$$

The law of the magnetic circuit, as applied to the armature, is considered in Chap. VII.

In the design of a dynamo, the armature part is generally schemed out first, and it remains to determine the dimensions of the field magnets and wire for the trial coils. It should be thick enough to carry a considerable current. The number of turns it contains must be known. This trial coil is to be excited by a current furnished by another dynamo, or a set of accumulators. In the circuit of this electric source is to be put an adjustable resistance or rheostat, so that the current can be varied, and an ampère-meter so that it can be read.

The brushes of the trial dynamo are to be set in proper position, and the armature run at the pre-determined speed. If the machine is to be shunt or compound wound, insert a voltmeter across its terminals. Place in its circuit (the armature's circuit) a resistance equal to 300 times that of the armature itself. This will approximately equal that of an efficient shunt winding. The exciting current is now to be increased until the voltmeter shows the volts required at the terminals. The run should be continued until the dynamo has acquired its normal working temperature. The exciting currents and the volts yielded by the dynamo are now to be noted. Now since the intensity of the magnetic field is proportional to the ampère-turns of excitation, the number of turns in the trial bobbin, multiplied by the number of ampères of the exciting current, will give at once the ampère-turns required in the real windings.

If there be more than one trial bobbin, care must be taken to have them all exactly alike—the same gauge of wire, and the same number of turns. It is immaterial whether the wire in the trial bobbins take only a few or a large number of turns. Thick conductors are generally employed for the purpose, seldom in more than two layers. The windings are usually put upon a shell or bobbin of sheet iron the ampère-turns to give the required magnetization. Although the length of the coils is necessarily fixed at a minimum, yet, when the cross section is ample, allowing say a square centimetre to each 12,000 lines, full allowance should be made for coil spaces, premising that a magnetizing coil may have a depth of half the core's diameter.

## Field Magnet Coils.

Since the electromotive force of the machine depends upon the speed, the number of turns of wire in series at once on the armature and the intensity (number of lines per square centimetre) of the field, it is to be assumed that the whole of these conditions are known before attempting to determine the ampère-turns requisite for the field magnet. The first two conditions are dealt with at some length in Chap. VII.

Certain considerations control the nature of the windings. The magnet coils must have the proper resistance in order to absorb the requisite energy. The current of the machine depends upon the windings of the armature, upon the section of its wire, radiation, and so forth. Hence, the machine's output in watts is limited entirely by the armature. Speed is limited by mechanical considerations. Two methods of finding the ampère-turns are practised, *a*, by experiment; *b*, by calculation.

(*a*) *Trial method of determining magnet winding.*—It is usual to erect the machine with its armature, brushes, &c., in proper order. Over the field magnet a pair (or one coil as may be required) of coils composed of two or three layers of pretty stout wire. Ordinary electro magnet construction will determine the size of different effects of various wire sections; the varying effect of different conductivities; and the varying thicknesses of insulating covering all combine against exact calculations. But certain matters are of common knowledge; *e.g.* that the depth (radial) of the coil should not *exceed* (it seldom attains) one-half the diameter of the core, and that the wire be of *sufficient* size to carry the current without *overheating*. It may be worth mentioning that any excess of copper over the section that will fulfil this latter condition may prove injurious instead of beneficial, because it diminishes the number of available turns in a given space. The wire is generally made thick enough to carry between 1,000 and 1,500 ampères to the square inch. If the coil be shallow the greater density may be allowed without overheating. If it be deep the lesser density will answer the purpose.

A formula has been proposed by Professor Hering, in which

($a\,\mathrm{W}$) represent the armature turns obtained in the test.

$a$ = current in shunt magnet of finished machine.

$\mathrm{W}$ = total number of windings or turns on each section of the magnet of the finished machine.

$\mathrm{R}$ = total resistance of the magnet coils of the finished machine in legal ohms.

$\mathrm{V}$ = volts potential at the poles of the finished machine.

$d$ = diameter of the bare wire in mils (thousandths of an inch).

$l\,m$ = mean length of one winding in inches.

$l$ = length in inches of one winding of the lowest which is about the same as the periphery of

It is evident that the resistance is proportional to the total length, $W\,l\,m$, and inversely as the square of the diameter, and is equal to

$$R = 50{\cdot}13 \frac{W\,l\,m}{d^2}\,\theta$$

in which $\theta$ is the specific resistance, that is the resistance in legal ohms of one metre of copper wire of one square millimetre cross section, at 0° C.; the constant 50·13 contains the reduction factors.

By Ohm's law

$$R = \frac{V}{a}$$

therefore $$\frac{V}{a} = 50{\cdot}13 \frac{W\,l\,m\,\theta}{d^2}$$

from which $$d = \sqrt{\frac{50{\cdot}13\,(a\,W)\,l\,m\,\theta}{V}}$$

from which the diameter can be calculated directly from the ampère windings ($a$ W) and the potential, if the mean length of one winding is known.

In connection with this subject it should be remarked that *a series dynamo is working at a maximum when the current in the armature = the current in the external portion of the circuit. Resistance of the magnet should be rather less than that of the armature.*

*In a shunt dynamo the current in the shunt should not exceed* 5 *per cent. of that supplied for useful purposes. The shunt should have from* 300 *to* 1,000 *times the resistance of the armature.*

*In a compound dynamo the resistance of the series winding should invariably be less than that of the armature.* In well-proportioned machines it is never more than two-thirds.

(*b*) *By calculation.*—Taking the law of the magnetic circuit to be

$$\text{Magnetic flux} = \frac{\text{Magneto-motive force}}{\text{reluctance}}$$

("Magneto-motive force" means the force of magnetization possessed by the current), we may now consider the following equations, in which the letter $i$ is used for the strength of the current (number of ampères); S for the number of spirals in the winding; $l$ for the length of the core; A for the area of cross section; N for the number of magnetic lines; $\mu$, as before, to express the permeability of the iron; and $\Sigma$ the sign of summation:

$$\text{Magneto-motive force } \frac{4 \pi S i}{10}$$

$$\text{Magnetic reluctance } \Sigma \frac{l}{A \mu}.$$

$$\text{Magnetic flux} \ldots . \text{N} = \frac{\frac{4 \pi S i}{10}}{\Sigma \frac{l}{A \mu}}$$

If we take the number of spirals and multiply by the number of ampères of current, so as to get the whole amount of circulation of electric current expressed in so many ampère-turns, and multiply by $4 \pi$ and divide by 10 in order to get the proper unit (that is to say, multiply it by 1·257), the result gives the magneto-motive force.

The number of ampère-turns required to force a given number of magnetic lines through a given magnetic circuit is as follows, using the same symbols:—

$$\text{S}\, i = \frac{\text{N} \cdot \Sigma \frac{l}{A \mu}}{1{\cdot}257}$$

That is, the ampère-turns equal to the number of magnetic lines required multiplied by the sum of the magnetic reluctances divided by the constant 1·257. This constant is stated to be due to the length, $l$, being expressed in centimetres, the area in square centimetres, and the permeability in the usual numbers. For inches and square inches the constant is to be taken at 0·3133, making the formula:

$$\text{S}\,i = \text{N} \times \Sigma \frac{l''}{\text{A}''\mu} \times 0{\cdot}3133$$—Dr. S. P. Thompson.

*By calculation based upon the heating effect of the current.*—It is equally important to possess a means of determining the currents that can be carried by coils of wire when the wire is varied in thickness or the coil is varied in size. Forbes * prepared two coils of the same size, but rolled with wires of different diameters, so as to occupy the same volume and to have the same weight. Then, if the number of turns on each bobbin is considerable, the length of wire is proportional to $\frac{1}{\text{D}^2}$ (D being the diameter of the wire), and the cross-section is proportional to $\text{D}^2$, hence the resistance of each coil is proportional to $\frac{1}{\text{D}^4}$, and the heat developed in the circuit during a unit of time varies as $\text{C}^2\,\text{R}$ or $\frac{\text{C}^2}{\text{D}^4}$. But the radiating surface of the two coils is the same; whence, if the temperature be the same in both, the heat lost by radiation and convection in a given time is constant, and the heat created in unit time must be constant.

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* Paper read at the Society of Telegraphic Engineers, "On the Prevention of Overheating," &c.

Whence $\frac{C^2}{D^4} = a^2$, where $a$ is constant,

and $C = a\,D^2$;

*i.e.*, to attain the same temperature with equal-sized bobbins, the current varies as the section of the wire.

To put the truth of this law to the test, two copper tubes were prepared with flanges at each extremity, and closed at one end, and wound with equal weights of two kinds of wire of different diameters. Filling one with water, and inserting a thermometer, the current was increased very slowly until a fixed temperature, sufficiently high, was steadily maintained. The tangent galvanometer was then read off. Afterwards the same temperature was attained with the other coil in the same way. The law above stated was exactly confirmed: the tangents of the angles were proportional to the squares of the diameters.

It is thus comparatively easy, in any case, to calculate the heating of a coil when we know its cooling surface and its resistance.

Let $\rho$ = the resistance of a coil in ohms at the permissible temperature,
$S$ = the surface exposed to the air measured in centimetres,
$t$ = the rise in temperature,
$C$ = the current in ampères.

$$\cdot 24\ C^2 \rho = \text{heat generated} = E\,t\,S,$$

where $E$ is M'Farlane's constant varying from ·0002 to ·0003. The latter value may be taken. If 50° C. be the permissible rise in temperature

$$C = \sqrt{\frac{\cdot 0003 \times 50 \times S}{\cdot 24 \times \rho}} = \cdot 25 \sqrt{\frac{S}{\rho}}.$$

*N.B.*—It must be remembered in practice that the resistance (cold) must be increased (according to the law of varying resistance due to heat) to give $\rho$.

Example :—The resistance of the field magnets of a dynamo is 1·5 ohms cold, and the surface exposed to the air is 1 metre : find the current to heat it not more than 50° C. Here $S = 10{,}000$, $\rho = 1{\cdot}8$ ohms, and $C = {\cdot}25 \sqrt{\frac{10{,}000}{1{\cdot}8}} = 33{\cdot}5$ ampères. Those who are accustomed to handling dynamos will know that this is very much what we actually find, and it gives us confidence in the applications of theory.

It is generally known that an external surface of coil of 223 square inches will continuously dissipate a watt (or volt ampère) of electrical energy when the temperature of the coil is 1° Fahr. above that of the surrounding air. The capacity of the surface for dissipating heat is directly proportional to the temperature of the coil above that of the air. In other words, every square inch of coil surface would dissipate a watt of energy at a temperature of 223° Fahr. above that of the surrounding air. Or the rule may be formulated

$$W = \frac{1}{223}\, t\, S = {\cdot}00476\, t\, S.$$

In which $W$ represents the watts lost in heating, $t$ the temperature (Fahr.) above the surrounding air, and $S$ the surface in square inches.

# CHAPTER V.

## DETAILS RESPECTING EXCITING COILS.

In Chap. IV. (pp. 64-66) will be found the necessary equations for finding the ampère-turns required for any given degree of magnetization. Having found the number of ampère-turns, the determination of the correct size of wire, and the space to be occupied by it, appears a comparatively simple matter. It is assumed that it is only necessary to find the size that will carry the required number of ampères without over-heating. Nevertheless, the finding of these values may present some difficulty.

The first rule to remember is that a small current of one ampère, flowing one hundred times around the core of the field magnet, will have precisely the same magnetizing effect as a current of ten ampères flowing around it ten times only. Let us consider a simple case, which will settle the question whether the wire wastes energy when fine and economises it when thick. Suppose an exciting coil, having one hundred turns of wire, say of such a size as will carry sixteen ampères without becoming heated. This coil will have a certain magnetizing effect, it will consume a certain proportion of the energy, and it will have a certain number of ohms of resistance. Now, suppose ıat all of these values have been noted, and that the magnet has been re-wound to the same dimensions of coil with a wire of one-half the former diameter. This coil will take four times as many turns (four hundred) to fill up the space. The wire will be four times as long, and it will have one-fourth the sectional area of the first wire. It will carry, therefore, a current of only four ampères (at the same current density as before). But as this current flows around the core four hundred times, the ampère-turns will be the same as before. Thus, multiplying the turns into the ampères gives in the first and second cases sixteen hundred ampère-turns. Now, the current density being the same, the waste upon resistance will be no greater in the second case than in the first.

So long, then, as the ampère-turns are provided it is of no consequence in the final result whether the wire be fine or thick. But it is essential that an economical proportion be held between the section of the wire and the current it is intended to carry. And it must not be overlooked that, while the magnetizing power increases in direct proportion to the current, the heating effect increases as the square of the latter. Hence, to avoid waste, it is important to fix upon some economical current density. This is generally made as great as is practicable. There are certain conditions that may be said to control this. The most important condition is *depth of coil*—in other words, the thickness of the coilings. A winding of one or two *layers* only would be called a shallow coil; a winding of many layers would form a deep coil. Now, the cooling effect of the air-radiation from the coil will be more effective in respect to the shallow coil than it would be in respect to the deep coil; while the former would rapidly part with its heat, the latter would retain it to a much greater extent. The same remarks apply to the insulating covering. Substances, as silk or wool, of low heat-conductivity, would retain the heat longer than the cotton which is generally used in covering dynamo-wire. In a machine for high tension working, the insulation of the coils will be thicker than in a dynamo for currents of low tension, and this also will have its effect. Now, dynamo builders are generally in agreement in allowing from 1,000 to 2,000 ampères per square inch sectional area of the conductor—that is, the general practice is to allow from one-thousandth to two-thousandths of a square inch of conductor to each ampère flowing around the coil. The higher density is very commonly exceeded, but in coils of one layer only, as in the single-layer series coils commonly superimposed upon the shunt windings in a compound dynamo. The following table gives the current density in (or carrying capacity of) the various commonly used sizes of wires at both 1,000 and 2,000 ampères per square inch.

TABLE OF CURRENT DENSITIES AND SECTIONAL AREAS OF DYNAMO WIRES.

| Standard Wire Gauge. | Sectional Area, sq. inch. | Diameter inch. | Current at 1,000 amps. per sq. in. amps. | Current at 2,000 amps. per sq. in. amps. | American Wire Gauges (Nearest). |
|---|---|---|---|---|---|
| 7/0 | ·200 | ·500 | 200 | 400 | .... |
| 6/0 | ·175 | ·464 | 175 | 350 | 0000 |
| 5/0 | ·150 | ·432 | 150 | 300 | .... |
| 4/0 | ·125 | ·400 | 125 | 230 | 000 |
| 3/0 | ·100 | ·372 | 100 | 200 | 00 |
| 2/0 | ·090 | ·348 | 90 | 180 | .... |
| 0 | ·080 | ·324 | 80 | 160 | 0 |
| 1 | ·070 | ·300 | 70 | 140 | .... |
| 2 | ·060 | ·276 | 60 | 120 | 1 |
| 3 | ·055 | ·252 | 55 | 110 | 2 |
| 4 | ·0425 | ·232 | 42·5 | 85 | 3 |
| 5 | ·0375 | ·212 | 37·5 | 75 | .... |

TABLE—*continued.*

| Standard Wire Gauge. | Sectional Area, sq. inch. | Diameter inch. | Current at 1,000 amps. per sq. in. amps. | Current at 2,000 amps. per sq. in. amps. | American Wire Gauges (Nearest). |
|---|---|---|---|---|---|
| 6 | ·0275 | ·192 | 30 | 60 | 4 |
| 7 | ·0250 | ·176 | 24·5 | 49 | 5 |
| 8 | ·0201 | ·160 | 20 | 40 | 6 |
| 9 | ·0163 | ·144 | 16·3 | 32·6 | 7 |
| 10 | ·0128 | ·128 | 12·8 | 25·6 | 8 |
| 11 | ·0105 | ·166 | 10·5 | 21 | 9 |
| 12 | ·0085 | ·104 | 8·5 | 17 | 10 |
| 13 | ·0060 | ·092 | 6·6 | 13·2 | 11 |
| 14 | ·0050 | ·080 | 5 | 10 | 12 |
| 15 | ·0040 | ·072 | 4 | 8 | 13 |
| 16 | ·0032 | ·064 | 3·1 | 6·2 | 14 |
| 17 | ·0024 | ·056 | 2·4 | 4·8 | 15 |
| 18 | ·0018 | ·048 | 1·8 | 3·6 | 16 |
| 19 | ·0012 | ·040 | 1.26 | 2·52 | 18 |
| 20 | ·0010 | ·036 | 1·0 | 2 | 19 |

In the ordinary coils used for exciting field magnets having only a moderate depth, the rise of temperature after one hour will not exceed an average of 50° Fahr. above the surrounding air at a density of 1,000 ampères to the square inch. But it is useless to cite rules (as is often done) in respect to this. The conditions vary, and a number of matters contribute to the result, which cannot easily be foreseen. In the specifications for dynamos it is usual to stipulate that the exciting coils shall not exceed, in full work, a temperature 100° Fahr. above the surrounding air, and this condition is easily complied with.

When the conditions of supply respecting the dynamo are that it shall give a constant current (as in series machines for arc lighting), the larger the gauge of wire the less the waste in heat. On the other hand, when the conditions of supply are that the dynamo shall maintain a constant potential (as in a shunt machine for incandescent lighting), the longer the wire the less will be the energy wasted as heat.

Again, for series dynamos (constant-current working) the magnetizing power of the coil is not dependent upon the *gauge* of wire, but is controlled by its length. When the conditions of the machine are for constant potential (shunt dynamo) the magnetizing power of the coil is independent of its length, but is controlled entirely by the gauge. In other words, it is essential to employ a thick wire, in a small number of turns, when the whole output of the machine passes around the magnet, as in an ordinary series wound dynamo. On the same principle, both series and compound wound machines must be wound (the latter in the series coils only) with thick wire. The conditions are precisely analogous to the cases of an ampèremeter intended to measure *current*, and a voltmeter intended to indicate E.M.F. or volts.

*Length of the Bobbins.*—It has long been known that a magnet with a considerable length of core possessed a greater attractive strength than one with short limbs. But the superior effect is not due to the length of the core. It is due entirely to the fact that long magnets are furnished with longer magnetizing bobbins, containing a greater number of turns than short magnets. It is well known that field magnets cannot be made too short. The shorter they are the less their magnetic reluctance. But there is always a well-defined limit to this condition. It is impossible to get upon the limbs of an exceedingly short magnet the turns of wire requisite to provide the magnetizing force needed to project the magnetic lines through the armature. In other words, we must have the proper number of ampère-turns upon the limbs, and these must be wound to a convenient depth, so as to provide for radiation of heat. In the best dynamos the exciting coils seldom or never have a depth (from the surface of the core to the outside surface of the coil) exceeding one-half the diameter of the core (if round). There are many old time-honoured rules to be found in the text-books respecting the dimensions of electro-magnets, and amongst them several which lay the depth of bobbin windings at various values, from the full diameter of the core to one-fourth its diameter. These may be safely neglected, and attention given entirely to the convenience of the case and the question of the emission of heat. It is, of course, advantageous to employ a high current density for many reasons already discussed. Hence dynamo builders, in many cases, design the depth and gauge of the wire to allow of the highest safe temperature.

*Field Magnet and Armature Insulated Wire.*—Cotton-covered copper wire is almost invariably preferred for all common dynamo work. While cotton may be said to be a sufficiently good insulator, it conducts heat away quicker than silk. But the cost of the latter renders its employment prohibitive, except in special cases. It is important to use wire neatly covered. If the insulation is not uniform, irregularities will occur in the winding, which will increase with each layer coiled. Double cotton-covered is generally preferred, but this must not be too thick. Perfect covering is far more important than merely thick covering. The aim of the coverer should be to insure tight and perfect coating of the wire in the case of both windings of cotton. Several inventors have applied for patents for this process.

The conductivity of the wire is a most important matter. It should in no case be under 95 per cent. of that of absolutely pure copper, and is frequently higher. It should not be "hard drawn." This makes it extremely stiff and resilient, and therefore very unmanageable in the case of winding an armature. It should be soft, round (if of that section), and smooth on the surface. The reputed gauge of the wire is frequently not the actual gauge, so that this point should be tested before making calculations. A very slight difference in size makes a very great difference in resistance or carrying capacity.

Wire coverers deliver dynamo wire in quantities of several hundred-weights (usually 1, 2, 4, and 6), wound upon wooden drums in continuous lengths for these weights. In special cases it is varnished in addition to the cotton covering, but this is generally left to the later stage of the work, so that the varnish is applied after winding. Paraffin wax, although one of the best insulators known, has too low a melting point to be applicable for general dynamo work. Rubber varnishes are, generally speaking, open to the same objection, although they are sometimes used. A good, hard, and quick-drying japan varnish, or, for cheaper work, bitumen varnish, is to be preferred.

*Operation of Winding.*—The first matter to be attended to in winding the bobbins is to ensure that there shall be no possibility of metallic contact between the wire and the iron of the magnet, or the metal of the reel or former. Reels are sometimes cast whole, flanges and body in one. It is difficult, however, to obtain castings sufficiently thin. Waste of space between the wire and the core is a great fault in a magnet. This fact leads many builders to wind direct upon the iron; but that can only be effected if the form of the core admits of it; and it is open to the objection that, in view of a possible future fault, it would be necessary to take the machine apart. The general practice is to wind the coils upon reels of the shape of the cores. The tube or body is preferably made in thin sheet brass, which must be slit up one side so that the reel shall not form a path for wasteful induced current under the variations of the field magnet current in shunt and other dynamos. The flanges or ends are usually cast in brass, and should be similarly slit, both slits corresponding in position in the finished bobbin. Non-metallic material is sometimes used in both body and flanges.

Insulation of the core and reel is effected by varnishing, and by a layer of Willesden paper, or thin vulcanised fibre, or sheet asbestos. Sometimes strong canvas is used. The interior of the flanges are similarly covered, but to three times the thickness.

In winding cores of shunt machines, the wire being long and thin, the assistance of a winding machine is sometimes called in. This consists of the usual bobbin mandril and to-and-fro guide, the latter being moved either by a cam, as in the American machines, or by a screw. Hand-guiding is, however, the common practice in this country. The reel, or frame, or core, as the case may be, is put upon a mandril in a back-geared lathe, and a slow motion of rotation is thus imparted to it. In the commencement of the winding, if the extremity of the wire is to be taken out through the flange—a very common plan—the channel or hole should be lined with a porcelain or fibre tube. In winding on the wire it must be put into position under some tension. But the pull must not be greater than suffices to fully straighten the wire. It may happen that, in imposing too much tension, the wire may be *stretched*, and thereby made thinner and longer than was intended. The tension arrangement generally consists of a grooved pulley, a foot or more in diameter, around which the wire takes one turn. Friction is put upon the pulley by means of a flat disc, pressed upon it by a large volute spring and screw.

# CHAPTER VI.

## *FORM OF THE FIELD MAGNET.*

FROM the foregoing considerations respecting the magnetic circuit, inasmuch as it affects the field magnet, it will be clear that a high figure of conductivity in this circuit is of equal importance with low resistance in the armature itself. The form of field magnet best fulfilling this requirement will have a short, thick core, few or no joints, and large pole-pieces. The material must, to secure a maximum conductivity in a minimum sectional area, be of the softest iron. The "grain," or texture of the iron, must run parallel to the lines of force through the core.

*Single Circuit Magnets.*—The course of the magnetic circuit in all the earlier forms of the dynamo was that due to a horseshoe, or similar shape. Here we have the lines of force flowing, as it were, from one pole, through the core, direct to the other pole, as through an arc. Wilde's early dynamos had this form. It has lately been adopted by Edison and many others. Its two most common shapes represent a horse-shoe, or U magnet; (1) with its poles downwards, as in Wilde's and Edison's dynamos, and (2) with its poles upwards, as in Kapp's latest dynamos. The chief fault of the early field magnets lay in the false notions then entertained of the essential requirements of the core portion. The development of the theory of the magnetic circuit opened the eyes of electrical engineers to the defects of field-magnets. It made clear what was before an untranslated page, and removed the objectionable factor of empiricism from the rules of construction.

The theory dictates that not only must the core be of the softest and purest iron, but that it be of the largest practicable cross-section, *and form, as nearly as possible, a closed magnetic circuit.* Formerly it was considered correct practice to make the circuit of a considerable length. The investigations of Drs. J. and E. Hopkinson, however, revealed the fact that not only was reluctance thereby increased, but that magnetic leakage occurred, to a great extent, from the long circuits. Practice and theory together now dictate that the circuit shall be as short as possible, consistent with allowing space for the exciting helices.

There is one great fault in the inverted ∩ form employed by Wilde and Edison, and to which we have before alluded. We refer to the inevitable loss, by leakage, that results from attaching the polar-pieces to the necessary cast-iron bed-plate, even although there be interposed a deep footstep of zinc or other non-magnetic material. This consideration has led many of our best dynamo builders to abandon the earlier ∩ construction, and to invert the magnet. The temptation to place the poles downwards is very strong. It refers, and is due, to mechanical considerations. The lower the bearings of the armature the less the vibration, and the machine becomes altogether more rigid. This fact led Siemens and

Halske to place their well-known horizontal pattern dynamo with its magnet as close to the bed-plate as possible. But, with rigid frameworks, this objection to high armature bearings need not apply. It has, therefore, become the rule to place the magnet with its poles upward, and to make it—from other considerations—as short or stumpy as possible.

The advocates of the Edison or Wilde style of magnet, however, contend that it is practicable to obviate appreciable magnetic leakage by improved methods of connection with the bed-plate. But their strongest argument appears to refer to the armature. It is well known that in many dynamos the "drag" of the magnetic field in such constructions as are under consideration, tends to pull the armature forcibly *towards the yoke* of the magnet. This is equivalent to saying that the field is not symmetrical, and that it is strongest across that region of the armature chamber nearest to the exciting coils. This fault has been combated by setting the armature *out of circle*, and practically placing it a trifle nearer to the *extremities* of the poles than before, with the intention of equalising the magnetic pull. In the case of a dynamo with a ∩ magnet it is contended that this unequal pull *supports the weight* of the armature, enabling it to run practically without heaviness upon its bearings. From an engineer's point of view this would be of considerable advantage.

It is frequently said that a field-magnet has *salient* poles. This implies that the latter project merely, and it is generally used to distinguish this type of magnet from those having what has been termed *consequent* poles—a term often used to denote field magnets of the earlier Siemens and Gramme patterns.

A perfect magnet core should have no joints. Mechanical difficulties, however, render the accomplishment of this, in many cases, impracticable. Thus, instead of the Edison magnet being bent from one long bar, it has been found preferable to form it in substantially five sections. These are the two limbs, which are made of sufficient length to receive the exciting coils; the yoke piece, which is of much larger sectional area than the limbs, and the two pole pieces, also made of greater section than the limbs. Experience dictates that if there be *joints* they must be as *perfect* as possible. Contact, surface to surface, must be as good as planing and scraping can make them, otherwise there will be a good deal of loss by reduction of the sectional area at those points. The case is quite similar to that of an indifferent contact between an electric circuit wire and its binding screw. Experience also points out the necessity for yokes in any form of magnet being of sufficient sectional area. Many of the early forms of field magnet were deficient in this respect.

But it is far more important to observe that whatever shape the field magnet assumes it is not *divided.* To work economically the ironwork should form one solid core, and not a series of bars. In relation to this the mind reverts to the horizontal pattern of the Siemens dynamo, in which the magnet was composed almost exclusively of iron bars, excited by a common helix—a form of magnet now abandoned.

The practice of the present time is strongly in favour of three conditions respecting the ironwork of dynamo field magnets. These are, *a sufficient cross-section*, *a short circuit*, and a pattern as *simple* as possible—as nearly of the pattern of a simple horseshoe magnet as practicable. Complicated forms are, and have been, very common. These generally contain a number of joints. Each joint introduces an additional chance of waste and weakness; and it can readily be supposed that in such dynamos as have thus a complex, built-up magnetic circuit, the cost of the magnetic field, in energy, is considerably greater than it should be.

*Cast-iron Field Magnets* have been very common. The low magnetic permeability of cast-iron, as we have already seen, is a sufficient reason for its condemnation for this purpose, except in exceptional circumstances. The temptation to use castings in lieu of forgings is, however, very great, and where *weight and bulk* are of no consequence a cast-iron field magnet may prove nearly as economical as one of wrought-iron, costing considerably more. There appears, however, to be one source of loss which the low permeability of cast-iron per square inch may compel dynamo builders to recognise. A bulky magnet requires a considerable length of wire to encircle it—probably one-third more than that used for a wrought-iron magnet of similar power—and it is conceivable that this, by introducing extra electrical resistance, may well prove a constant source of unnecessary expense.

*Edges and Corners* are to be avoided in the ironwork. These frequently protrude sufficiently to act, to a certain extent, as poles, and cannot therefore be regarded but as a source of loss. This is especially the case when the useless corners protrude from the pole pieces.

*The Most Efficient Section of Core is undoubtedly a Circle.*—This, of all forms, includes the greatest proportional mass of iron to periphery. Hence, the circular form will require the least length of exciting wire. Owing, however, to structural reasons, cores and yokes of rectangular, or oblong section, with rounded corners, are very commonly employed.

*Pole Pieces* are very generally of cast-iron; and for this reason they are made of considerably greater cross-section than the core. Protruding edges, as before spoken of, must be particularly avoided in the polar terminations. The shape to be given to them must have for its object the *concentration* of the magnetic lines *upon the armature*, and not their diffusion through the air. For this reason the flanks or "horns" of the pole pieces, where they come nearly together in embracing the armature, must be thinned off, so that the inductive loss, or leakage from pole to pole, will be reduced to a minimum. To produce a uniform field a good deal depends upon the exact shape given to the pole pieces. When the magnetic field is weak the maximum induction takes place, not uniformly over the surface, but at the edges of the pole, or at two points apart in the pole piece. A more intense field, with chamfered polar horns, obviates this defect. When the poles are properly formed it is advantageous to make them embrace almost four-fifths of the armature's periphery. In certain forms of dynamo, however, it is found advantageous to reduce this proportion.

*The Armature Chamber or Bore* through the pole pieces should always be tooled out. It is usual to mount both polar blocks upon the face-plate of the lathe, separated to the required distance. The bore is then turned out quite true, a trifle larger than the circle described by the armature. If the pole-blocks are to be fitted upon cylindrical cores the core-holes should be turned out similarly. The surface contact between the two should be as perfect as practicable.

### Consequent-Pole Magnets.

Hitherto we have considered only the simple form of magnet, having two limbs salient. If we take an iron ring, without a break but with projections as pole pieces, it will be practicable, by means of appropriate windings, to concentrate therein, at two opposite points, magnetic poles.

The ring really, then, consists of two electro-magnets, with their like poles together. This arrangement gives rise to what has been termed consequent poles. An electro-magnet, with consequent poles, was first applied to dynamos by Gramme, who embodied this construction in his constant-current machine as early as 1870.

Consequent-pole field magnets were very commonly used in dynamos until the investigations of Hopkinson and others revealed the fact that this construction generally involved considerable avoidable loss of energy. As commonly carried out, the design embraces a considerable length of magnetic circuit, as it includes—in the Gramme dynamo—the end-frames of the machine. In addition to the extension of the circuit this form of magnet commonly involves a considerable number of joints—always a weakening feature in field magnets. Experience proves that although this combined form of field magnet presents many advantages from a constructive point of view, they are more than counterbalanced by the drawbacks already mentioned. An ideal field magnet would have the shortest possible circuit, the greatest possible sectional area, consist of the softest possible iron, and be entirely free from joints.

The diagrams of the different combined magnets here given, in which N S represent the poles, Y the yoke, and *a* the armature space, with cross lines depicting the coils, show very clearly wherein the chief defects lie. Efficiency is sacrificed to constructive considerations in many of them. Cast-iron is used where wrought iron should be employed. Some of them meet the difficulty half way, and put wrought-iron cores to cast-iron yokes—here joints are inevitable. But if cast-iron is to be employed at all its only useful function is that of a yoke, or connecting piece, or as pole pieces. Cast-iron, owing to its low permeability, as we have already shown, is wrongly employed as a core.

*Cast-iron Magnets* may be made as powerful as wrought-iron magnets, but not of equal size or weight. Since we may regard the cast magnet as one-third larger than the wrought magnet, there will be a proportionate difference in the resistance of the exciting coils required to encircle them.

If cast-iron is to be used at all, and it is employed, say, as a yoke piece, its section must show at least the above proportion to that of the core. Cast-iron magnets may be considerably improved by being annealed. The annealing may, in some cases, be carried so far as to convert the metal into "cast-malleable," by which means the permeability may be increased considerably. Dr. Hopkinson found, in his experiments, that wrought-iron showed 18,250 lines per square centimetre, 12,408 lines in malleable

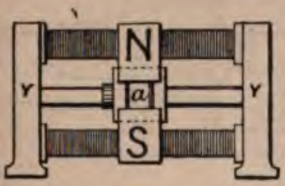


Fig. 23.—Gramme Type.

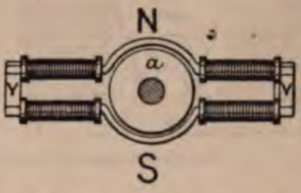


Fig. 24.—Siemens Horizontal Type.

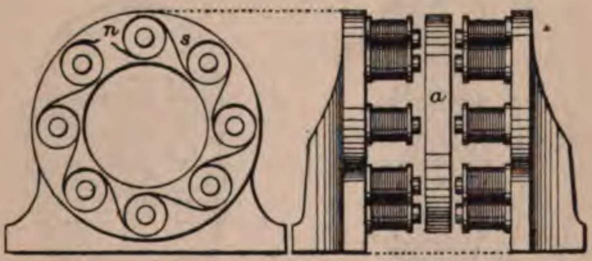


Fig. 25.—Type of Alternating-Current Dynamo Field Magnets in General.

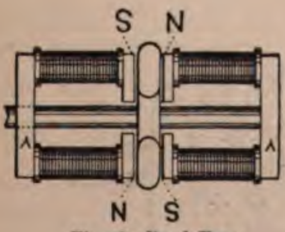


Fig. 26.—Brush Type.

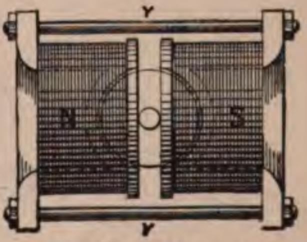


Fig. 27.—Thomson-Houston Type.

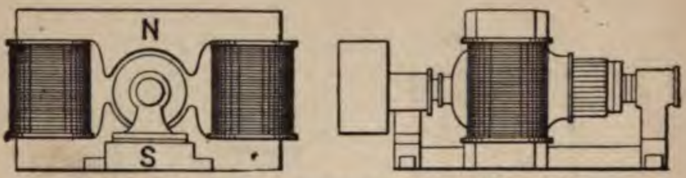


Fig. 28.—Mather and Platt Type (" Manchester " Dynamo).

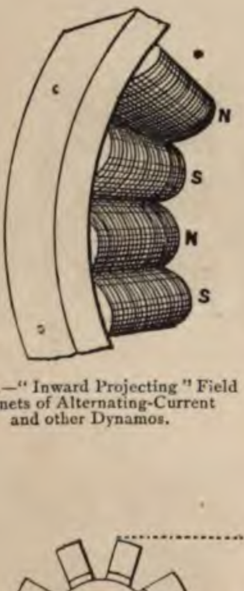


Fig. 29.—" Inward Projecting " Field Magnets of Alternating-Current and other Dynamos.

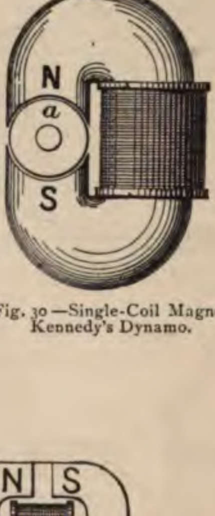


Fig. 30.—Single-Coil Magnet, Kennedy's Dynamo.

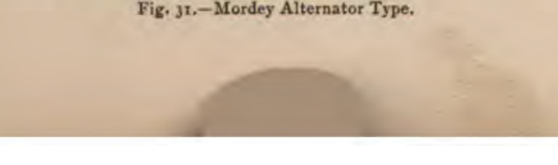


Fig. 31.—Mordey Alternator Type.

cast-iron, 10,783 lines in grey cast-iron ("white metal"), and 10,546 lines in mottled (or common) cast-iron. Mitis iron is a material of recent introduction. It consists of wrought-iron, containing a small proportion of aluminium. It is easily cast, and is likely to be employed largely for the cheaper classes of dynamos. It is probably not superior to malleable cast-iron in permeability, but its actual value has not yet been determined.

### Right and Left-handed Coilings.

It appears scarcely necessary to state that the coiling, as such, has any influence in determining the sign of the poles. A north pole is not necessarily produced by either direction of coiling. *The direction of the current* is, of course, the determining cause. If a magnet be exhibiting the wrong poles, the coils need not be disturbed. It is only necessary to reverse the connections with the electric source. In some cases dynamos may, by accident, become reversed. That is, the residual, or "permanent" magnetism may not accord with the direction of rotation. The pole-signs may easily be found by presenting to them the needle of a small compass, and any fault may either be rectified by changing the connections of the coils, or by passing through them a strong enough current to reverse the polarity. The latter is the better expedient.

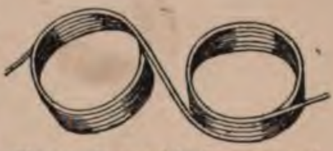


Fig. 32.—Course of the Current around the limbs of a U Magnet.

*Direction of the Helix Cross-Connections.*—No difficulty need be experienced in determining the connections of a complex form of field magnet. If we take a long bar, and coil it from end to end with a right-handed winding, this helix will always run right-handedly, whether we bend the bar into a horseshoe shape or not. Such a magnet would commonly be excited by two deep windings upon the straight limbs, as it is not found particularly advantageous to continue them over the bend, or yoke. The connection between the coils would cross from one link to the other in the form of the letter ∽, as depicted in Fig. 32.

# CHAPTER VII.

## THE ARMATURE.

AN armature may be defined as a *closed conducting circuit, capable of revolving in or cutting a magnetic field.* But a much clearer apprehension of what an armature must be is obtained from the conception of a magnetic circuit. The field is merely part of this circuit. The armature is a link, nearly completing the circuit.

A magnetic circuit, incomplete, is provided. The gap is called the magnetic field. It is a region across which lines of force are projected. Any metallic body set rotating so that it cuts these lines of force will have induced in it currents of electricity. The moving body may merely consist of a circle of any conductor having an axis set transversely to the lines of force. This is the simplest kind of armature. It is also the least effective.

An arrangement of this kind is depicted in Fig. 33. It may be regarded as the simplest form a dynamo can assume. It is only useful for purposes of illustration.

In its revolution it cuts the lines of force twice, and the direction of the current is reversed twice. Two short impulsive currents are induced in it. The strength of these currents reaches a maximum at the moment when it is cutting the greatest number of magnetic lines. It is clear that as this occurs twice in a revolution there will be two points of maximum and

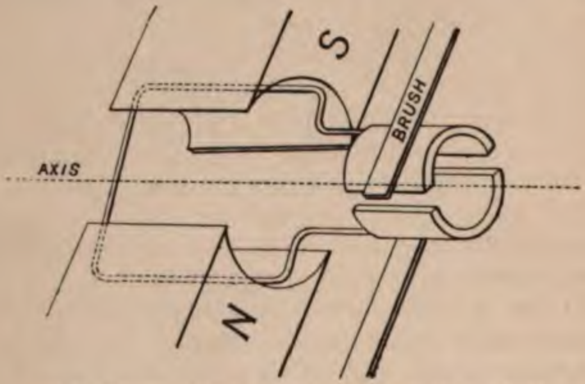


Fig. 33.—Diagram of Single Loop Armature in a Magnetic Field.

two points of minimum strength of current. It is at the minimum points that the reversal takes place.

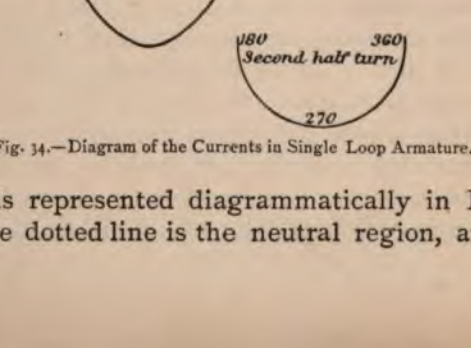


Fig. 34.—Diagram of the Currents in Single Loop Armature.

This is represented diagrammatically in Fig. 34. ere the dotted line is the neutral region, and from this, upon either side, the impulses spring, rising to a maximum electromotive force and again falling to the line of least action. The first and second half circles, marked in degrees from 0 to 180, show that at the points 90° and 270° the electromotive force induced is at a maximum.

The currents produced by such simple arrangements have two drawbacks. They alternate in direction, and they are not continuous. The first fault may be rectified by collecting the currents from the surface of a two-part commutator; the second drawback is inseparable from an armature of this kind.

Without further elaborating our conception of the armature we may suppose the simple loop to form a single convolution around a mass of iron, revolving freely with it in the magnetic field. The effect of this would be to transform the simple loop with its core into an electro-magnet. The currents induced in it would remain of the same character. But they would be considerably augmented in force. We may inquire the reason of this. In the first case our magnetic field was an empty air-space, except when the loop cuts through it at each turn. In the second case it is occupied by a mass of iron. We have regarded the air-space as a gap, simply, in the magnetic circuit of the inducing magnet. To project lines of force through this gap consumes considerable energy; in other words, the magnetic field will be comparatively weak. The gap, then, offers great *reluctance* to the lines of force. If we desire to reduce this reluctance, the simplest expedient appears to be to partially bridge it across with a mass of iron, this being the substance best adapted for the conveyance of the lines of magnetic force. The number of lines of force will now be considerably augmented; the reluctance in the field will be chiefly composed of two narrow air gaps, or that necessary "clearance" space between the armature and the polar faces.

*It is not necessary that the iron core should revolve.*—In our conception of a magnetic circuit it merely serves to reduce the magnetic reluctance of that circuit. It may be regarded as a partial continuation of the body or core of the magnet itself. It influences the result very little whether it moves around with the conductor or not. The iron core of an armature is thus a means of bringing the lines of force in the field with increased power through the turns of the conductor.

*The iron core may be dispensed with by adopting other means of reducing the reluctance of the air gap.*—If the conductor, instead of forming a simple loop, having an axis transverse to the lines of force, be formed in a snail-like, flat spiral, the spiral may be moved bodily across the field, cutting it edge-wise. The air gap between the poles of the field magnet may thus be greatly diminished in breadth. It need only be wide enough to allow of the passage of the spiral. The width of this will be determined by the thickness of the conductor employed in forming it. A *very intense* magnetic field, having comparatively little reluctance, is thus possible. It is quite unnecessary, as practice has abundantly proved, to employ iron in any form in combination with an armature coil of this description.

With regard to the use of iron as a core for an armature, it may be remembered that from the earliest history of the magnetic machine its presence was considered practically indispensable. This arose from the description of armatures employed. They were all electro-magnets of some form. The first "*keeper*" or armature was merely a piece of iron employed to cross the poles of a magnet and so maintain the magnetic circuit by contact. The early experimentalists showed that if this keeper had wound upon it a few turns of insulated wire, every removal and replacement of it from the poles—or every break and make of the magnetic circuit—led to the inducement of a current in that wire. Before long steps were taken to give the keeper and its coil a motion, by mechanical means, across the poles of the magnet. Currents were induced as before, and from this germ has been evolved the iron-cored armature. The early experiments made with a view to obtain equal electrical effects from coils without iron cores were much less successful. We now understand the reason. It is clear that iron is not essential. But as everything depends upon the nature of the armature, and the disposition of the field, iron cores are necessarily largely used, and will probably always be employed for dynamos. As before stated, however, some of the most conspicuously successful dynamos have not a particle of iron in the armature.

## Commutator.

The simplest armature consists, as we have seen, of a single conducting circuit cutting lines of force. The currents it yields are undulatory and alternating in direction. For many purposes the undulatory currents are unsuitable, especially if the rise and fall of the current-wave be slow. If, however, the waves occur with great rapidity, or many hundreds to the second of time, such an undulatory current may find many uses. The alternate direction of the current is a less serious objection. It may easily be commuted to a uniform direction. But alternating-direction currents of rapid recurrence are in common use for feeding incandescent lamps. This class of current is, indeed, in high favour for that purpose. It is clear that, in order that the to-and-fro current shall not be observable in the light emitted by the lamp, its wave or "phase" shall be rapid. This "periodicity" is frequently as high as 200 alternations per second of time.

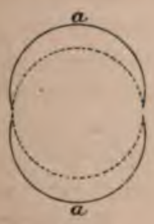
Continuous currents are yielded by several descriptions of armature. But a large number give off alternating currents. It is generally required to commute these to take a constant direction with respect to the exterior (or useful) portion of the circuit. The most usual arrangement to meet this consists of a divided copper sleeve insulated from, but rotating with, the shaft or axis. The coils have their extremities connected to the several portions of this sleeve, and the currents are taken from the surface by two springs of copper or brass, bearing upon its opposite diameters.

If the armature consist of two parts, or only one complete circle, as in our first example, the commutator will be in the form of a copper tube, split into two equal portions, longitudinally. (This form of commutator was illustrated and explained at p. 27.) These are insulated from the shaft and from each other. The collecting springs (or "*brushes*," as they are generally termed) are fixed in such a position that at the instant the current experiences a reversal the two half tubes shall exchange springs. It will thus be clear that one of the springs must always receive the positive current (as we may for the moment term it) while the other invariably receives the negative current. This simple device was one of the earliest improvements made in this class of machines after their first invention.

If the armature were to consist of two loops instead of one only, the commutator would then have four separate parts to receive the four extremities. But such commutators are only of the simplest kind, and are no longer used in dynamos. The connections of the wires and loops involve no problem. In many machines the arrangement of the wires forming the circuit of the armature are very complex, and we cannot at this early stage enter upon the details.

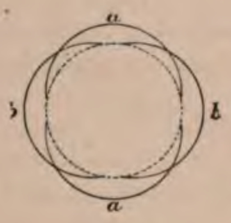
## Continuous Current Armature.

We have already considered the faults of the simple single-loop armature. Its current consists of two



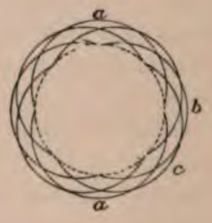
*Impulses due to one loop in armature*

Fig. 35.



*Two loops in armature*

Fig. 36.



*Four loops in armature*

Fig. 37.

sharp impulses. Only a very feeble effect can be produced by this arrangement. If, however, two loops be arranged at right angles to each other, four impulses will be given in each revolution. While the first loop is passing through the weakest part of its circle—

giving its minimum effect—the second loop will occupy the maximum position. The object aimed at is to so arrange the loops that there is always a maximum current flowing. In Figs. 35, 36, and 37, the impulses due to a single loop, a double loop, and a four-part loop are depicted. In Fig. 37, the impulses combine to form a nearly continuous current. The letters *a b c* trace the positions of the impulses.

It is plain that if a larger number of coils or loops be employed, they may be so disposed, at regular intervals in a circle, as to ensure that one or more of them occupies at any period of the revolution the point of maximum effect. This is the secret of the great success that has attended the introduction of the Pacinotti ring principle (Gramme's armature) and that of the Alteneck drum armature. Both of these famous armatures yielded absolutely continuous currents. The same effects have of late attended the development of several other kinds of armatures. It is regarded as an essential condition in a well-designed dynamo.

The circle being filled with active conductors, it becomes a study of the deepest interest how best to combine these among themselves, and how to deliver the effects to the collector or commutator.

These considerations apply more particularly to the forms of armature in which loops or circles of conductor, having an axis through them transversely to the lines of force, are employed. The case respecting connections is somewhat different in what are called disc armatures and one or two others.

We have already seen that a conductor wound up n the form of a flat spiral, or in any other flat ring shape, will have induced in it an electric current upon passing bodily through a magnetic field. In the majority of disc armatures the coils are arranged at equal distances around the periphery of a disc or wheel. The principle of the disc armature is very old, but it has lately been revived in the construction of alternating dynamos. The disc is arranged upon an axis, and generally rotates in a vertical plane. In order to ensure the *continuity of current* in this class of armature the field magnets are constructed in an entirely different way from that already spoken of. While the loop or drum armature is usually mounted between the poles of a single massive electro-magnet, the disc armature is furnished with multiple magnetic field set up by a large number of small electro-magnets. These are arranged in two crowns or circles, concentric with the disc, and upon either side of it, as previously explained and illustrated (p. 87.) By the simple expedient of ensuring that there shall be a greater number of armature coils than field magnets, the essential condition of continuity is secured. The arrangement is such that two or more of the disc coils are at the maximum while others are at the minimum. In fact, as in a well designed loop armature, there is no perceptible undulation in the current.

This arrangement is represented in Fig. 38. Where all the coils, *c c*, &c., are joined in series and their terminals taken to a pair of collector rings, *r r*, rotating with, but insulated from the shaft, the coils are generally wound alternately right and left-handedly.

In relation to the simple question of continuity of current, there remains to be mentioned that class of armatures generally known as *ring* armatures. This class has been the subject of a great deal of attention from writers on electricity. The questions involved in the action of a Gramme ring armature are, indeed, among the most fascinating in the whole science. We cannot dwell fully upon it here, and will, therefore, content ourselves with a sketch of the conditions.

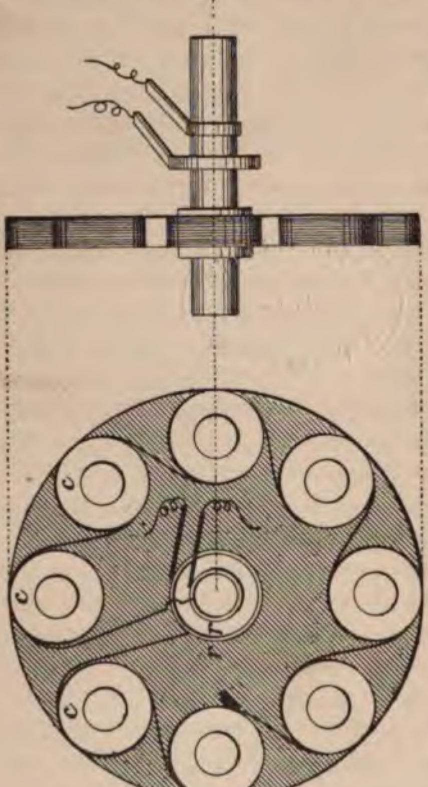


Fig. 38.—Arrangement of Coils, &c., in Armature of Alternating-Current Dynamo.

The ring armature (Gramme's pattern) is well known to consist of an iron core, of ring shape, surrounded with an endless helix of insulated wire. It is mounted upon an axis passing through its centre, and is caused to revolve in a vertical plane—after the manner of a wheel—between the two poles of a large field magnet, as already illustrated and described at p. 16. It may be considered, for our present purpose, that the currents are simply collected by two springs, pressing upon opposite diameters of the ring so as to make contact with the helix. The current evolved in this arrangement, in its revolution in the magnetic field, has not inaptly been likened to a fall of water, free from undulations and reversals. As the ring revolves, its iron core experiences a continuous magnetization at two opposite points. The core, indeed, forms two magnets with their similar poles connected as one.* Here, then, we have the case of a helix, in effect moving continuously over two consequent magnetic poles (for we may at once ignore the fact that the iron core itself moves, since we are dealing with the magnetic lines of force only), and at the same time cutting the lines of force projected from the field magnet. The effect of this is to cause an assumed flow of current towards two opposite diameters of the ring at points cut by a line drawn at right angles to the poles of induction. The collecting springs or brushes, touching these two points of flow, convey the current to the external work and complete the circuit.†

* It should be remembered that a magnetic pole may be concentrated in any part of an iron circle, as well as at the extremity of a bar. The former is very generally spoken of as a "consequent" pole, the latter as "salient."

† The reactions in the Gramme ring have given rise to a good deal of discussion, and diversified opinion exists as to the precise conditions of generation of current. Although the problem is full of interest, our space forbids a full consideration of the case in these pages.

## CHAPTER VIII.

### *THE ARMATURE CORE.*

THE two classes of armatures in which iron cores are employed are mainly *Drum* Armatures, or those having a cylinder shape, and *Ring* Armatures, or those of annular form. The greater number of armatures belong to one or other of these two kinds. The Drum Armature has assumed the leading position in dynamos for constant current. The earliest attempt to form a drum armature appears to be that of Sturgeon (p. 8), who produced an iron shuttle, with the requisite windings of insulated wire. At a later period Siemens and Halske introduced their well known H girder armature (p. 11), a device which gave a considerable impetus to the use of magneto machines at that time. This form has been so frequently described that (since it is now obsolete except for small machines) it need not further occupy our attention. At a later period followed the cylindrical iron core of Alteneck, and the famous Ring of Gramme, which, however, had been anticipated by the toothed ring of Pacinotti (p. 14). This latter was unquestionably the first attempt to form an armature capable of either yielding a continuous current or of acting with a continuous mechanical effect as a motor. The core consisted of a ring or rim of iron having sixteen tooth-like projections. These formed very wide teeth: the spaces between them wide "pockets," in which the induction coils were wound. Thus tooth and coil alternated—sixteen of each. The coils were of insulated wire, and were, as a whole, carefully isolated from contact with the iron rim. The only difference between Pacinotti's core and the later celebrated armatures of Gramme and Brush lay in the fact that Gramme dispensed with the projecting teeth, and, in common with Brush, set his ring in a vertical plane (while Pacinotti adopted the horizontal position).

### Lamination of the Iron.

If a *solid* core of iron be employed in any form of armature the result of its action will be the evolution of great heat. In any armature generating large currents in the presence of a mass of iron it becomes a difficult matter to eliminate the heat. To dissipate the heat by currents of air, or by water circulation (as was tried in some of Wilde's machines) is clearly a mistake. At best, it is but the dissipation of energy, and must necessarily be wasteful.

*Foucault or Eddy Currents.*—The researches of Dr. Frolich* first drew attention to the wasteful effects of heat in armatures, and to the true cause of this rise of temperature. He pointed out that much, if not most, of the unaccounted-for loss of energy in generators was to be attributed *to the generation of wasteful eddy currents in the iron composing the core.* The conception of these currents soon admitted of proof. It was shown that not only did they arise wastefully in the mass of the core, but may even prove a drawback in the conductors surrounding it. It has been shown that in armatures of extremely low resistances, where the conductors take the form of solid copper plates or bars, there may be a considerable loss from eddy currents in the conductors themselves, apart altogether from the loss incurred by non-lamination of the iron core. In the large armatures used for incandescent lighting this defect caused a considerable waste of energy, and was otherwise troublesome. More recent researches of Dr. Frolich and others have indicated the existence of these currents, chiefly in the form of vortices.

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* *Elektrotechnische Zeitschrift*, vol. ii., p. 174, 1881.

The case of eddy currents in the conductors around the armature has been most successfully met by a system of lamination. The solid copper bars of the earlier dynamos are usually superseded by strap or band copper, every layer of which is separately insulated. When conductors become large a distinct advantage is gained by this method, apart from the question of eddy currents. It is found that a smaller weight of copper will, when laminated, yield maximum effects.

*Heat of Core—or Eddy Currents in—detrimental to Magnetic Induction.*—It is well known that magnetism in iron or steel is quickly and completely destroyed by heat. Obeying the same law in a relative degree, it is known that hot iron has a much lower magnetic susceptibility than cold iron. To magnetize a hot core, therefore, calls for a greater energy in the field, and this explains why a dynamo frequently falls off in performance after it has become heated. Apart from this, however, the effect of heat in the armature is the certain destruction of the insulation. The process may be gradual, but it is, nevertheless, certain. Under favourable conditions the heat may even quickly destroy the insulation.

*The Laminations.*—During the evolution of the common induction coil, or Rhumkorff's inductorium, several experimentalists pointed out that a considerable gain could be secured by subdividing the iron core. A core slit in two, longitudinally, was found better than a solid bar, and a bundle of rods or wires was found to be a still greater improvement. This refers to bars or masses *magnetized in the direction of their length, and not transversely.* The distinction is important.

The cores of armatures used in dynamos are seldom magnetized longitudinally. The transverse magnetization calls for a different arrangement of the laminæ. The cores of all common forms of armatures *should be laminated in planes parallel to the lines of force in the magnetic field, and never at right angles thereto.* In most cases this is equivalent to sub-division in planes normal to the currents induced in the armature. The reason for this is to be found in the fact that the induction tends to cause eddy currents directed at right angles to the field. The sub-division must be arranged to obviate this, and to render impossible any current directed at right angles to the lines of force in the field.

*Lamination of Drum Armatures* is very satisfactorily effected by building up the required cylinder from a large number of thin washers or discs of iron. The softest charcoal iron should be used for this purpose. In order that the discs may become magnetically discontinuous it is usual to separate each pair with a paper washer, or a washer of mica. In inferior dynamos the discs are simply varnished. It is possible that the latter method, if it can be carried out without distortion of the washers, might become a sufficient protection in itself.

Drum armatures are frequently constructed after the manner of Pacinotti's ring, with projections. In this case the washers are stamped out in the required form, and clamped together, so that the projections and interspaces form ridges and channels for the reception of the coils. This method is more frequently followed in the formation of ring armatures of the deep-cylinder type. It is depicted in Figs. 39 and 40. Fig. 39 represents one of the washers, which, in addition to the slotted central shaft-hole, is pierced with four ventilating apertures, for the purpose of cooling the armature by the admission of air. These discs are usually built into a solid cylinder (*d d*, fig. 40), between two flanges of gun-metal, also furnished with projections, or ribs. The whole arrangement shows a compact cylinder, with longitudinal ribs, *r r*, and ventilating apertures, *v v*. To a certain extent these ribs may be regarded as Pacinotti's pro-

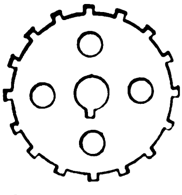

Fig. 39.—Disc from Ribbed Armature Core.

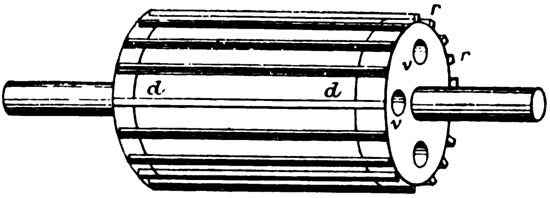

Fig. 40.—Ribbed Armature Core.

jections. They are usually as deep as the windings. They serve admirably as divisions, forming regularly-spaced channels for the reception of the coils. Edison or Siemens armature cores are built in the same way, except that the washers are not furnished with teeth. The end flanges, however, are provided with equally-spaced ribs, to facilitate the winding.

In Edison's armature (drum type) the plain washers are threaded upon the shaft, against a suitable end-flange, and when the pile is completed the whole is compressed from the opposite end by a pair of lock-nuts, turning upon threads cut upon the shaft. This is the general method of construction. Many modifications of it have failed to show that it can be materially improved upon. If longitudinal bolts be used to compress the discs apart from the shaft, care must be taken to insulate them from each other, and from the discs themselves. If this precaution be neglected, induced currents will circulate in the system of bolts, giving rise to as much heat and waste as the lamination is intended to obviate. Experience points to the plan first given as the better of the two.

*Lamination not without Disadvantages.*—The magnetic discontinuity of iron cores may, from another standpoint, be regarded as a disadvantage. Although its observance in the case of armature cores, or in any part of a dynamo subject to changes of magnetic strength is *indispensable*, it introduces an increase of magnetic reluctance or resistance. It decreases the effective cross section of the armature. In many forms of armature it is difficult to adhere rigidly to the rule that the planes or lines of lamination shall be parallel to the lines of the inducing field. For this reason wires are seldom employed for purposes of subdivision. The direction of magnetization must always determine the plane of subdivision. When an armature revolves this will, in most cases, be normal to the axis. Subdivision that violates these principles may be considered of doubtful advantage.

*Lamination of Ring Armatures.*—Gramme's armature core consists, as already stated, of iron wire, wound upon a suitable former, until a flat, annular core is built up. The wire being varnished before being wound may be regarded as a fairly complete protection against eddy currents. But this method is not regarded as entirely satisfactory. Theory dictates that the core should be built up from a large number of thin iron rings to the required breadth. Each ring should be separated by paper or mica from its neighbour. This latter method is preferable as reducing the magnetic reluctance of the ring. Either of these methods of subdivision is adapted to a core to be *magnetized across its diameter*. This method of mounting the Gramme ring, it will be seen, forms the ring virtually into two magnets with two consequent or combined poles.

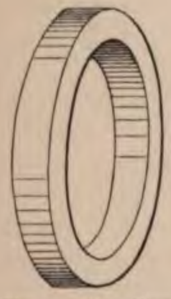
Fig. 41.—Ring Core of Gramme Armature.

Gramme armatures are built in two leading forms. These are the *ring* armature simply, having a core of the form depicted in Fig. 41, and the *cylinder ring* armature, in which the core assumes more or less the form of a cylinder or drum. The core of this design takes the shape shown in Fig. 42. As a rule the sharp edges of these ring cores are carefully chamfered or rounded off—not shown in the diagrams—and channels are milled or planed out of the interior, at the required intervals, to receive the arms of the driving arrangement centred

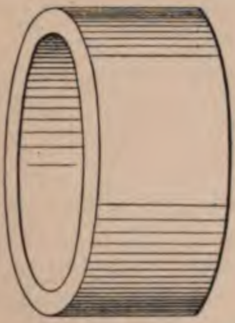

Fig. 42.—Cylinder or Elongated Ring Core.

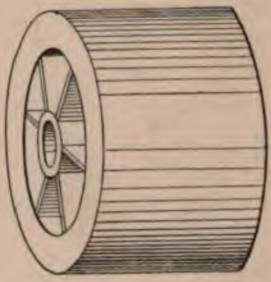

Fig. 43.—Cylinder Ring with Driving Spider.

upon the shaft. This, in the improved and later dynamos, usually consists of a "spider" of bronze, as represented in Fig. 43, having arms as thin as may be permissible, in order to obviate the taking up of space required for the enveloping coils.

Ring cores of the *Brush* type are magnetized in a very different way. Here the lamination is most advantageously disposed parallel to the axis of the ring. In the early Brush machines the armature core consisted of a ring of cast iron. The double side projections, or teeth (known as Pacinotti projections) were carefully slit, and the body of the ring itself was partially slotted in a plane parallel to the driving shaft. This form of ring heats considerably.

Fig. 44 represents a Brush's ring, with twelve Pacinotti projections, *p p*, without windings or axial arrangements. The pockets into which the coils are wound are formed with parallel sides, so that the "teeth," *p p*, are of a somewhat tapering form. This kind of core has been very extensively used. The magnetization in Brush's dynamo is parallel to the line *p p*.

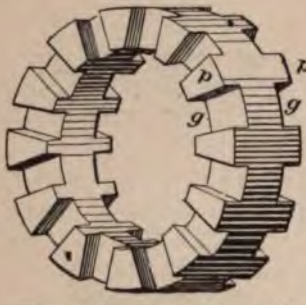

Fig. 44.—Ring Core with Pacinotti Projections.

In a later improvement of this armature the lamination is effected as follows:—

A strong foundation-ring is taken of a size exteriorly to form the interior diameter of the active ring. A ribbon of soft iron, having a thickness of 1·5 millimetres, is secured parallel to its surface. This ribbon is wound upon the foundation to the size of ring required, 45 convolutions being employed. But as the Brush ring has two sets of Pacinotti projections, one from either side, those are formed by inserting, at suitable intervals, H shaped pieces of iron. These project from either side to the required distance. They are so disposed as to leave "pockets," or indents, for the coils, having parallel sides. This plan was adopted so that the coils might be of parallel shape. Insulated radial bolts are passed through both ring and projections, securing the whole into a compact body. The details of construction, however, vary with the particular forms of ring to be laminated. This ribbon method of building up ring armature cores intended to be magnetized parallel to their axis is likely to have extended application.

These examples will suffice to show the devices that experience has proved effective in the elimination of eddy currents and the heating of armatures. That the lamination of the core is of considerable advantage beyond the mere stoppage of the wasteful currents is shown strikingly in the case of Brush's dynamo. A machine of the old type, built to supply sixteen arc lamps, is found, when fitted with the laminated armature, to be powerful enough to feed twenty-five lamps.

*Influence of the Pacinotti Projections.*—Considerable discussion has been evoked in various publications bearing upon the utility, or otherwise, of the projecting teeth first applied to a ring armature by Pacinotti, and more lately modified and elaborated by several experimentalists. The researches of Prof. Thompson, Mr. Crompton, and Mr. Esson all tend to emphasise the general opinion that the toothed ring is superior to the smooth core. The advantage is doubtless attributable to the influence of the projections in reducing the magnetic resistance, in affording direct paths for the lines of force across the field. It has also been pointed out that the projections tend to cool the core by carrying the heat from its interior.

## Material of the Armature Cores.

From the considerations already discussed, it is evident that soft iron is the only admissible metallic core for an armature. By the word "core" is understood the central mass of the armature intended to play a part in its action. A core of wood, or brass, might be employed; and even the latter might not prove detrimental to the performance of the armature if it were suitably laminated. But such non-magnetic cores would be without effect in the resultant electrical currents. They would act as mere formers, or bobbins, to receive the conductors composing the armature.

The material must be *iron*, because that metal offers least resistance to the transference of the lines of force across the field. In other words, it has least magnetic reluctance; it is easily and rapidly magnetized and demagnetized. The iron must be *soft* or ductile under the hammer, because a fine quality of Swedish or charcoal iron possesses much less magnetic *reluctance* than harder varieties. It thereby reduces the magnetic resistance, so to speak, of the whole armature. If a hard quality of iron or steel were employed a certain damming-back of the lines of force across the field or gap would result. It would acquire a certain degree of permanent magnetization; it would, as a whole, fail to perform with that degree of *mobility* throughout its mass which is a characteristic of the best kind of armatures. If the core be composed of any of those metals or alloys called non-magnetic, such as brass or copper, the magnetic reluctance would be practically infinite, and it would entirely fail as a core acting by magnetic induction.

## The Core regarded as a Link in the Magnetic Circuit.

A very clear conception of what an armature core must be is to be obtained from a correct discernment of the lately-developed theory of the magnetic circuit, as applied to the dynamo. A partially complete magnetic circuit exists—there is a gap as yet. This is the field magnet; the gap the magnetic field itself. Across its space are projected lines of force. The magnetic resistance of this air gap is very great. Within the gap, nearly filling it, but still free to revolve, is placed a metallic body of peculiar construction. From one point of view its function is to complete the magnetic circuit. It is possible, although there yet exist two air spaces, to impel the lines of force across the air gaps: they are simply to be regarded as resistances to the lines of magnetism.

The wider the armature gap the greater its resistance, and the less intense the field therein. When it is wide, the magnetic continuity across can be most easily ensured by filling it with the most permeable magnetic conducting substance. As this implies the substance having the least known magnetic resistance, soft iron is chosen.

It will now be plain that the magnetic field gap—or armature gap—must not be too wide to ensure a maximum intensity. It must be extremely narrow, *if nothing is to be used to reduce its resistance*. If the armature-conductors are not to be coiled upon a core of soft iron they must form a thin body—a flat ring or a disc. This rule applies with much force to all dynamos in which iron-cored armatures are dispensed with.* But when the armature assumes the form of a cylinder a narrow field gap is impracticable. A much larger proportion of the whole magnetic circuit must then be cut out. As far as is practicable the circuit must be again completed. This is accomplished by the insertion of the largest practicable, and least resisting body of iron. This iron core carries upon its surface certain coils of conductors. The air gaps across which the lines of force have to be driven are, in width, equal to the distance of the iron core from the electro-magnet faces. Hence the narrower this air space is made the better. It is made as narrow as possible, but the practicability of this is limited by two considerations. (1) The enveloping induction wires must be arranged in *number* sufficient to yield the electromotive force required from the dynamo—"*number*" is equivalent to depth of windings. (2) The induction wires must be as *thick* as possible, so as to offer the least possible electrical resistance to the currents they carry.

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* In some of the largest of the famous Ferranti dynamos, the distance between the opposing magnetic poles, the width of the field, is scarcely over half an inch.

## Cross Section of the Core.

The particular form of armature will always determine several points. (1) Whether it is to be iron-cored or not; (2) if iron-cored, the disposition and planes of the lamination. But there is one observation that appears common to all kinds of iron-cored armatures: it refers to the cross-section of iron employed. *The cross-section should be as great as possible*, for reasons discussed in the preceding paragraph. This is a condition which modern practice has proved to be of the greatest importance. It has been frequently violated in many otherwise well-designed dynamos. In some of the earlier Siemens machines, for example, the iron core merely consisted of a thin iron cylinder, overspun with iron wire, providing but a small area or cross-section to carry on the important work of maintaining the continuity of the magnetic circuit.

If the armature be cylindrical, it can be cored and laminated with a considerable cross-section by the use of the iron discs previously spoken of.* No better kind of core for this class of armature has ever been devised. A tube of iron would prove a very objectionable kind of core. Iron wire laid parallel to the axis is still worse, since its plane would be *across* the lines of force, tending to cut them up. Iron wire wound upon a wooden foundation has frequently been used, and answers fairly well, if of sufficient depth; but it is open to the objection that the continuity it offers to the lines of force is imperfect. Moreover, unless the wire be of square section it will occupy useless space, and thereby not comply with the above rule.

For the same reason iron wire is not so suitable for a ring armature, such as Gramme's, as a core built up of thin discs. Armatures consisting of wheels, carrying near the edge a series of bobbins of wire, present a difficult case. If iron cores are to be employed they must not be solid. Split tubes are too light. Bundles of wires are the most suitable, but are, for manufacturing purposes, troublesome. These objections are the chief causes of the decline of this class of dynamo. Siemens was the first to dispense with the iron altogether, and narrow the bobbins down to mere discs of wire.

## Rules Appertaining to Armature Cores.

To sum up briefly the lines of best construction of an armature core, it must fulfil the following conditions:—

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* In the Edison-Hopkinson dynamo, 1,000 of these discs is employed for one armature.

1. It must consist of the softest Swedish or charcoal iron.

2. The iron must be laminated, and the laminæ separated by a non-magnetic substance, in planes normal to the axis, and parallel to the lines of magnetic force in the field.

3. Its cross-section must be as great as is practicable—there must be plenty of iron in the core.

4. The parts composing the core must be very securely attached to each other and to the shaft, to resist the powerful tangential drag exercised by the field.

5. Means of ventilation are advisable, although this is seldom requisite if the metal be suitably subdivided. It is frequently objectionable as diminishing the cross-section of the active iron.

### Classification of Armature Cores.

Iron-cored armatures represent by far the most important class. For practical purposes they may be divided into two main branches :—

*Drum Armatures*, iron-cored, had their rise in the semi-drum shuttle armature of Siemens. Modern examples are to be found in the Siemens drum-armature dynamo; in Weston's dynamo (the first in which projecting teeth were employed); in Edison's machine; in Crompton's drum machine; in Immisch's dynamo; in Paris and Scott's machine, and in numerous others.

*Ring Armatures*, iron-cored, had their origin in Pacinotti's machine. It was followed by Gramme's ring dynamo, and by that of Brush. One of the earliest was the *cylinder* ring dynamo of Maxim.

Some of the best known are the Bürgin cylinder ring dynamo—now called the Bürgin-Crompton machine; in Kapp's dynamo (cylinder ring); in Paterson and Cooper's machine (cylinder ring); in Schuckert's (flat ring) machine; in Gulcher's dynamo (flat ring), and in those of many other makers.

*Spherical Armatures*, iron-cored, are extremely rare. The chief representative of this type is the famous machine of Thomson and Houston. The armature is strictly spheroidal in form.

# CHAPTER IX.

## *ARMATURE WINDING.*

IN Chap. VII. *et seq.* are discussed the effects of revolving a single circuit of conductor within and across the lines of force in a magnetic field. Further, it was shown that, in order to obtain a continuous current, instead of two impulses during each revolution, the number of coils had to be increased. Thus an armature might be built up of circles of conductor, each one of which would deliver an impulse into the external portion of the circuit, so that the resultant current would be practically continuous.

Now, the electromotive force developed in a wire cutting lines of magnetism depends upon the number of lines it cuts per second. In other words, it depends upon the intensity of the magnetism and the rate or velocity of its revolution. Whatever this electromotive force may be, it can be very easily multiplied by multiplying the number of wires or loops. The force then can be doubled by having two wires in one loop, both passing through practically the same part of the field at the same time. We may thus indefinitely increase the electromotive force by employing multiple loops or oblong *coils* of wire in the place of single conductors. We may also determine the electromotive force by the *speed*, and by the *strength* of the *magnetic field.*

It must be understood that the word "*coil*" implies a wire taking several turns, and having only two extremities. These are attached to the collector or commutator as if the wire described one turn only.

From these considerations we may express the procedure in the case of determining the electromotive force in the following way:—

1. To obtain a *minimum* electromotive force (if required under given conditions of speed and magnetic field) use loops, or coils, of a *single turn.* This enables us to utilise the space by making these loops of very thick wire, thus diminishing to a minimum the electrical resistance of the armature.

2. Augmentation of the electromotive force is got (under given conditions as before) by *increasing the number of turns in each loop* or coil. The electromotive force is approximately proportional to the number of turns. But this increase of number of wires necessitates a diminution in the size of the wire to allow, in a reasonable space and depth, the number of turns in each coil, and also the number of coils required around the armature to yield a continuous current. The necessity to diminish the cross section of the wire results in a corresponding increase in the resistance of that wire. Hence:—

Armatures of low electromotive force are usually of insignificant resistance.

Armatures of high electromotive force are usually of considerable resistance.

In the early days of the magneto-electric machine, Mr. Wilde used to have for his large machine (as exhibited to the Royal Society in the year 1867) two armatures. One of these was wound with copper plate or band, and had few turns, and a low resistance.

It was called the "quantity" armature. The other was wound with many turns of insulated wire, and was of high resistance. It was termed the "intensity" armature. At the present time these armatures would be regarded as low and high resistance armatures, their performance as armatures of corresponding electromotive forces being understood.*

Without entering upon a consideration of the nature of the electric current, and the laws that define the relationship between electromotive force and resistance, it may be remarked that a dynamo is not necessarily giving a weak current, or a weak electrical effect, when working at a low potential (electromotive force). Nor must it be supposed that a dynamo yielding a very high potential is necessarily giving rise to powerful electrical effect. On the other hand, the output of the dynamo is measured in watts, which at once expresses its power; and two dynamos may be doing precisely equal electrical *work*, although evincing very different electromotive forces. Hence it is not necessarily a disadvantage to arrange an armature for low potential.

## Formula of Electromotive Force in Armature.

The following rule is sufficiently accurate for determining, in absolute units (C.G.S. system), the electromotive force that will be induced in the armature of a continuous current machine:—

If M be the *magnetization* (effective) through the armature, in other words the number of lines of magnetic force (measured by unit pole) impelled through the armature by the field magnet; and T the *turns* described by the armature wire making each coil, in other words the number of turns in circuit or series at once, counted from one collector bar to the other, or from brush to brush, and at the number of revolutions per minute $\therefore \frac{N}{60}$ = revolutions per second; then, E.M.F. standing for electromotive force,

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* The student must not, however, fall into the error of supposing that an armature of either low or high resistance will necessarily yield corresponding electromotive force.

$$\text{E.M.F.} = M \times T \times \frac{N}{60}.$$

This gives the E.M.F. in absolute units. For practical purposes these are reduced to volts by division by the number $10^8$.

Again, let V represent volts evolved by armature,

$$\therefore V = \frac{M \times T \times N}{60 \times 10^8}.$$

This applies to dynamos of the closed coil description, or those in which half the coils in the armature (approximately), as in Gramme's ring, are in circuit upon each side at once. A few dynamos, however, intended to give continuous currents, as Brush's machine, are wound upon the principle of throwing out of circuit the coils that are not for the moment active. In such cases it is necessary to count convolutions actually in circuit only.

### Determination of the Current.

The power of a dynamo is known in terms of its electromotive force (volts) and its current (ampères). The current will depend upon three matters:—

1. The electromotive force at its poles (volts).

2. The electrical resistance of the whole circuit in which the energy is expended. This includes the dynamo's own ("internal") resistance, made up of armature turns in series and field magnet coils, and the external work, as leading wires and lamps.

3. In certain cases, counter electromotive force, as the back pressure of accumulators being charged, or back E.M.F. from any other cause.

Let C stand for current in the external portion of the circuit;

E for the electromotive force of the machine.

$E_c$ for any counter electromotive force (in incandescent lighting this quantity may be omitted).

$R_i$, internal resistance of dynamo.

$R_e$, external resistance, leads, lamps, &c.

Then:—

$$C \text{ (ampères)} = \frac{E - E_c}{R_i + R_e}.$$

It is useless to occupy space by following a very general practice in books of giving several pages of ready-prepared "examples" of the application of Ohm's law of the circuit. Supposititious cases are always a questionable basis for such work.

The case of alternating-current machines is rather more complex, and will be treated later. But it may here be remarked that the rule relating to the E.M.F. being proportional to the number of turns in the coil (under given conditions of speed, &c.), is the same practically for the two machines. The armatures of alternators (of the multipolar type) are frequently, however, made of extremely low resistance by the expedient of employing only one circuit. But this circuit consists practically of many induction turns, as in Ferranti's dynamo. The *e.m.f.* when measurements are to depend upon the lines of force, is to be regarded as the region between any two opposing magnets, or the magnetic lines that pass between any north pole and any south pole across the plane of the armature. These considerations are, however, more fully treated in Chap. II.

### Proportion between depth of Windings and Diameter of Core.

In determining the number of turns in a coil upon the surface of any armature core it is important to remember that the size of the wire, that is, its sectional area, will limit the current it can carry in safety. To prevent overheating, the current may be as great as 2,000 ampères per square inch of sectional area. Many armature builders, however, exceed this considerably. The safe current will depend greatly upon the nature of the insulation, and the provision made for ventilation. In relation to this point it is necessary to remember that in loop armatures, such as those of the drum and ring type, where the extremities of the coil are really connected to two opposite collector plates or brushes, only half the current passes by the wire. This will be evident when we remember the disposition of the coil upon the surface of the core. From these considerations (regarding the number of coils as having been determined upon beforehand) the weight of copper that can be arranged upon the core can easily be settled.

With regard to the radial depth of the coils, measurements made upon a number of the best working constant-current dynamos show an average of depth to radial depth of core of rather over *one-*

*sixth.* This proportion is further useful in determining the cross section of the core itself. These considerations apply chiefly to drum armatures of the types already spoken of.

*Relation of the parts to each other.*—In order to fix in the reader's mind the relative positions of the parts of the ring armature, it may prove useful to represent

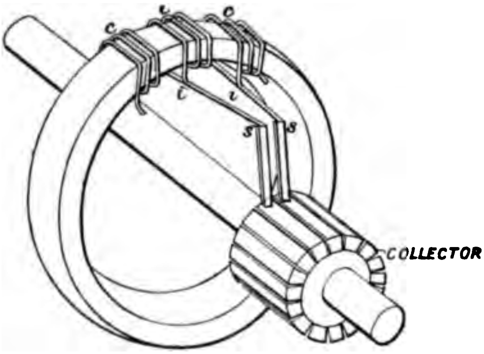

Fig. 45.—Ring Core with three Coils, showing connections.

them diagrammatically, as in Fig. 45, the three coils, *c*, having connections at *i*, and through conductors *s* (shown of abnormal length for the sake of clearness) to the collector lugs. Fig. 46 represents the coils and connections of one half of the ring, while in Fig. 47 is depicted a complete armature of the narrow or ring-core form.

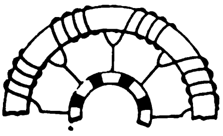

Fig. 46.—Diagram of Coils in a Ring Armature.

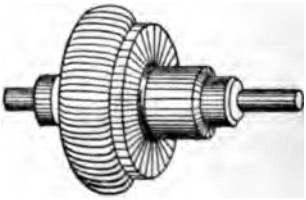

Fig. 47.—View of a completed (narrow Core) Ring Armature.

# CHAPTER X.

## *RING ARMATURE WINDING.*

HAVING already considered the reactions between the field and an armature of the ring type (p. 100), it now remains to discuss the methods adopted in practice in the winding of the ring.

*The Continuous Helix Method* was first practised by Gramme, and is the best known. The core, as we have already seen (p. 108), consists of a flat ring, composed of soft iron wire or washers.

*Insulation of the Core.*—The iron ring is heated and placed in a vessel of melted bitumen, until the latter has sunk into all the intricacies of the coilings. It is then removed, and the superfluous bitumen turned off. A long strip of linen, two or three inches in width, is closely wound upon the core to a depth of two thicknesses. This is finally saturated with shellac varnish, and allowed to harden. In some cases, in armatures intended for high tensions, the core is covered with indiarubber, which is finally vulcanised in position—a very excellent kind of protection.

*Rotation Mounting of the Core.*—The old French method was to leave the mounting until the ring had been wound, and to force it over a wooden drum, keyed upon the shaft. The objections to this plan are that, under the heating of the ring, the wood is apt to shrink, and finally to lose its grip upon the ring. Also, the insulation of the coils is apt to be injured by the pressure necessary in forcing the hub into position. American dynamo builders who have adopted the Gramme armature have effected a great improvement in the rotation mounting. This consists in substituting for the old wooden drum a gun-metal "spider," having four or six spokes radiating from a central sleeve-hub, keyed to the shaft. The arms of the spider are broad and flat in the axial plane, and are made thin enough to occupy but a small space between two adjacent coilings, as already illustrated and explained at p. 109. Two methods of attaching the spider to the core are in use. The older consists in fitting the ring closely over the arms, and fixing them in position upon it by U-pieces or gun-metal staples screwed from the periphery. The later method consists in winding the core direct upon the spider, the arms of which are shaped to receive the coilings in the required form. The circular shape is preserved by the insertion of segmental pieces, which are afterwards removed from between the arms of the spider. In either case the winding of the induction coils is conducted as follows :—

*The Coils of the Helix.*—We have already seen that the coiling of a ring armature does not consist of a single-wire helix. In order to gain electromotive force the helix really consists of several layers of wire. In order that the several sections of the coil as they cut the field may throw their accumulated force upon the collector at the right instant, the helix must be wound on in separate sections, each complete in itself. This is accomplished by arranging upon the ring a series of segmental coils, but each connected to its neighbour, so as to form a circle of bobbins in series.

The winding is done by hand. In order to facilitate the formation of the coils and their symmetrical arrangement, the ring core is accurately divided into the required number of sections by marking. The latter is so arranged that the arms of the spider fall between two coils. It is of some importance that this division of the circle shall be accurate, for if any one coil be larger than the others it will upset the electrical balance of the ring, and prove a source of trouble by sparking at the commutator. A pair of "*winding clamps*" are employed to define the width and shape of the coil section. The ring core is fixed in a wooden clamp in a vertical plane at the height of the operator's elbow. The winding clamps are fixed in position. A wire of the length required to form one coil is taken. If it be long and thin (when the dynamo is intended to yield high E.M.F.) it is wound first upon two shuttles as follows:—One end of the wire is taken and fastened in a notch in a wooden shuttle. One-half the wire is then wound upon this shuttle. Another shuttle is taken. The remaining end of the wire is fixed to it and wound up as before. One of the shuttles is then passed through the ring, and the operator proceeds to form exactly one-half of the coil by passing one of his shuttles the required number of turns through the ring. The other half of the coil is wound in the same way by winding off the remaining shuttle. By these means both extremities of the wire are gradually worked to the outside of the coil. There is considerable objection to winding the coil from one end, thereby leaving the inner extremity to be brought out between two coils. During the process of winding, the operator takes care to place his wires as closely as possible in the segmental chamber. After each layer is wound, a coating of quick-drying varnish is applied. When the coil is finished it is sufficiently firm to stand by itself as a segment upon the core. Both ends of the wire are brought out at the side where it is intended to place the collector. One of the clamps is now moved forward to another division of the ring, and another coil is wound in the same way. Care is necessary to exactly divide the wire, to ensure that all the coil-lengths shall be the same, and that the turns exactly complete the allotted space.

When every section is completed, the exterior is varnished. In order to prevent displacement of the coilings by the rapid motion of the ring, "*binding coils*" are placed over the segments. These consist of several turns of fine brass or steel wire wound tightly in three or more separate bands upon the periphery. These wire bands are finally soldered to obviate flying asunder. It should be noted that this binding wire must be as fine as is likely to effect the desired purpose.

In order to preserve throughout the required circular outline, and the concentricity of the segments, it will readily be supposed that particular care must be observed in so disposing of the wire that there shall be no difference between any two of the coils. The operator soon learns to fill *all* the space at his disposal, and this is the main condition. Space fillers of vulcanised fibre are generally placed between those coils from which the spider arms are absent, so equalising the positions.

*Breakdown of Insulation.*—Sparking may possibly occur between adjacent coilings if the E.M.F. developed by the machine be high. This is obviated by inserting divisions of thin varnished millboard, or sheets of vulcanised fibre, between the sectional windings. But the chance of a breakdown of the insulation is much greater through the core itself. Coils at opposite diameters will have potential differences as great as that of the machine. Sparking from coil to core, and from the latter to the diametrically opposite coil, may therefore occur. This can only be obviated by proper insulation of the ring prior to winding the coils. There is probably nothing better for this purpose (other than vulcanised rubber) than several layers of varnished tape, each layer being wound and varnished, and allowed to become dry separately.

*Operative Details of the Winding*—The number of coils should be as great as possible. This will depend greatly upon the size of the core, the thickness of the wire, and other considerations. In the section of this work treating of typical dynamos, details used in leading Gramme machines may be found. These form a very good basis in calculating the numbers of a new armature. It will be found that, as the interior of the core is smaller than the periphery, a winding of two layers deep upon the latter will, if it be closely arranged, necessitate a winding three layers deep upon the interior of the core. This introduces some irregularity in the arrangement of the wires passing over the ends of the core, and a good deal of judgment is necessary in disposing of the turns to the best advantage. In order to ensure a smooth and regular exterior, some makers cover over all irregularities by interposing a layer of vulcanised fibre between the final layer and that under it. An odd number of layers will be found preferable to an even number, because, if the winding be conducted from the middle of the wire as suggested, this brings the finishing extremities to the two ends of the coils ready for connection to the next coil on either side, and to the respective collector bars. The plan of working both ends simultaneously to the outside ensures that short circuiting in the coil will be almost impossible, and facilitates repairs. Some winders prefer to wind in parallel coil spaces, by the insertion of wedges of V-shape in the interior of the core, between the coils. This, however, wastes a good deal of space, and does not appear to offer corresponding advantages. The wooden winding clamps are made in several patterns. The simplest form a guide from the ends over the periphery only. Double clamps form a guide on the interior of the core also. In the early dynamos it was the practice to twist together, and solder, adjacent coil ends. In improved forms the ends are kept separate, and are screwed into separate holes, with set screws, in the extension arms from the collector bars. The final binding wires or "bands" are preferably made of hard brass wire. Before they are applied, there should be wound on bands of mica, suitably connected by cement. Silk ribbon is frequently used for this purpose, but a harder protection appears advisable. Vulcanised rubber or fibre appears to be suitable. It must be particularly noted that, unless the insulation between these bands and the coils be sufficient, short circuiting from one half of the armature to the other will take place. In the winding of coils of thick wire, good judgment is necessary in "placing" the latter.

Wooden wedges, with grooves or channels cut lengthwise of their face, will be found useful as beaters, to be used with a hammer, in forcing the wire into position. Compact winding, having no interspaces and a neat finish, are all very desirable.

### Causes of Sparking.

In most of the systems of winding of armatures two adjacent collecting cylinder strips represent respectively the two extremities of one induction coil. When the junction or insulation line of these two strips comes exactly under a brush, the latter touches both of them at once, and *short circuits* that coil. A momentarily strong current is thus set up in it. When, therefore, the brush leaves one of the strips, the short circuit is opened, and the *extra current*, due to self-induction, as well as the current normally due to its motion in the field, rushes across the breach, expending its force in a spark.

If, on the other hand, the brush were to be so constructed that it touched only one collector slip, it would then break contact with one slip before making contact with the next. This would have the effect simply of breaking the whole circuit momentarily, and would give rise to very destructive sparking. It appears essential, therefore, that the brushes shall bridge over, or short circuit, two slips or segments of the collector at once.

From these considerations it is evident that the remedy for sparking lies very greatly in the practicability of reducing the self-induction of the coils so short-circuited. It is necessary, in short, to provide that the short-circuited coils shall be as far out of the region of magnetic activity as possible at that instant. This implies that they shall not be actively cutting lines of force. The more *idle* the coil at the instant of short circuiting the better. In order that the idle coils may be out of the field, or nearly so, at the instant of contact, or short circuiting, the space between the extremities of the embracing horns of the field magnet must be carefully studied. If it be arranged that the coil be fairly within this space, and does not *cut* any of the magnetic lines, although they may *thread* through it, sparking will be reduced to a minimum. Self-induction, on the other hand, is best combatted by making each coil as short as possible, or, in other words, building the armature with the greatest possible number of coils and commutator strips.

*Collector* for Symmetrically Wound Ring.*—The collector consists of a number of segmental pieces of copper, insulated from each other, and rotating with the shaft. In the most improved forms the segments assume a narrow V-form, as illustrated and described at p. 26. There are as many segments as there are coils upon the ring. The segments are arranged so as to form a cylinder, and many ingenious devices have been introduced by different makers for the purpose of binding them together in that form. Between each pair of segments an insulating space is provided. In the earlier dynamos this space was filled with asbestos millboard. In later machines mica of good quality has been found preferable. The insulating space is very narrow; it is only essential that the segments be separated. A thickness of mica of $\frac{1}{32}$nd of an inch is generally considered sufficient, but it depends largely upon the electromotive force of the machine. There is little tendency to sparking between coils adjacent in a ring unless the E.M.F. be very high.

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* It is incorrect to call the collector of a Gramme or Siemens machine a commutator. The latter is an arrangement intended to *change the direction* of currents, and the term is not correctly applied otherwise.

A considerable *depth* of segment is desirable, because a collecting cylinder is constantly wearing down when in work, and it becomes necessary at intervals to turn off the roughened surface in the lathe. A collector of considerable depth, carefully built, will thus serve for several years' wear. The segments are made with outward projecting edges at either end. When in position these projections are engaged by a collar or flange of hard rubber or wood upon the shaft, having in its inner face a V groove to receive the segments. The other end of the collector is similarly held by a screwed insulating flange, made secure from turning by a lock-nut. Considerable care is requisite in fitting the mica. It must not only be of uniform thickness for all the divisions, but it must completely fill the space. Between the segments and the shaft is interposed a sleeve of some insulating material, as ebonite or vulcanised fibre or wood. Hence, every

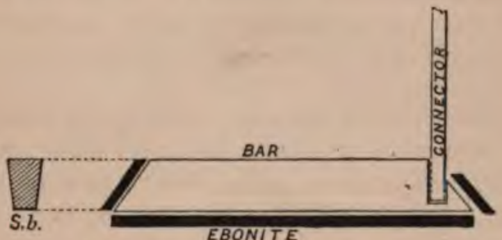

Fig. 48.—Collector Bar and its Insulation.

section is completely insulated from its neighbours, and from the shaft.

Fig. 48 is a sectional diagram of the positions of the collector, the insulating sleeve of vulcanised fibre or ebonite, and the insulation at the ends of the bar, when the latter is clamped tightly down to the sleeve and shaft. The connector or collector "lug" is shown fitted into a groove or slot turned in the bars. It is sometimes soldered there, or attached by a screw. But each maker may be said to have his own particular method of connection. S *b* is a section of the bar.

These collector bars, since they form, when assembled, a complete cylinder, are frequently made by casting a copper or bronze cylinder, and afterwards cutting it up in the milling-machine into the required number of segments. Later practice, however, has shown the superior wearing capacity of compressed *drawn* bronze or phosphor bronze. It is, therefore, becoming common to build collectors from "drawn bar" of perfect and uniform section, and of great tensile strength. Several different methods of fastening the bars are shown in the Chapters on Typical Dynamos.

The connections to the armature coils are generally effected as follows:—To each segment is secured a radial arm or lug of brass. The arms are of sufficient length to reach to the inner diameter of the ring. The upper ends of the arms carry connecting screws to receive the two wires—the finishing end of one coil, and the commencement of the next. Soldering was formerly resorted to for all these connections, but is now discarded in favour of screws.

*Collector Brushes for Ring Armature.*—The armature, shaft and collector form one body, rotating in its bearings. The currents evolved by the armature are taken off the revolving collecting drum by means of springs of copper or brass. These are usually called brushes. A line drawn through the armature axis, almost at right angles to another line parallel to the magnetic field centrally, gives the "line of collection," or the points of contact of the brushes. These two points are respectively those at which the potentials are theoretically highest and lowest. Slightly in front of this (in the direction of motion) the position of least sparking generally occurs. At that point the brushes are always placed. In some dynamos the "line of least sparking" and maximum electromotive force is parallel to the lines of the magnetic field. In most machines with ring and drum armatures it is at right angles nearly. The distance between the theoretical line and that of best collection is often spoken of as the "angular lead" of the brushes. This position is generally found by trial when the machine is running.

Whatever position the brushes may be required to hold with respect to the collector or armature, they must invariably (for the type of armature under consideration) be fixed in relation to each other upon a line passing through the axis at right angles. Hence, the points of contact must be exactly opposite each other. But as it is necessary to determine by experiment the point of best collection, a certain movement of the brush yoke around the axis is essential.

This is effected by forming the yoke upon a large metallic ring moving round upon a concentric hub. This ring is generally provided with a set-screw for the purpose of locking it at any desired point. A pair of arms, partly of insulating material, project from the ring to receive the brushes. These latter slide in grooves cut in the arms, and can be set by a screw therein. Each maker has his own particular device for this purpose, and for giving spring contact to the brushes. All that is essential is that the brushes shall touch the collector exactly opposite each other, and that they have the requisite elasticity, and are insulated from each other.

The brushes themselves usually consist of a number of hard-drawn copper wires, or a bundle of copper strips. The object of subdividing the points of contact is to distribute the destructive sparking over a considerable area, and to ensure that this area is in contact with the collecting brush.

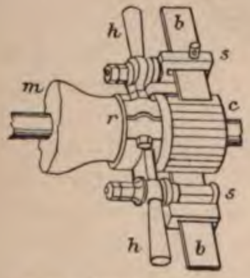

Fig. 49.—Details of the Single Brush Yoke or Rocker.

Fig. 49 depicts the whole arrangement generally called a brush rocker or yoke. *m* represents a portion of the main casting around a turned hub of which the split collar, *r*, upon which are cast the arms or handles *h h*, moves. By slackening a set-screw these arms may be set in any desired position concentric with the shaft. The arms carry angle spindles, *s s*, forming brush holders, through which the brushes, *b b*, slide, and are set by screws. The cylindrical lined body, *c*, is the collector itself. The brush yokes, *s s*, are really swivelled upon their axis, and are provided with a small "hold-on" spring, the function of which is to [illegible] the brush against the collector. In the most [illegible]oved forms of brush rocker the same spring, by means of a well-known "knuckle" movement, is made to act also as a "hold-off" spring. Thus, when it is desired to keep the brush away from the collector, it is pulled away forcibly until the knuckle is thrown over by the spring.

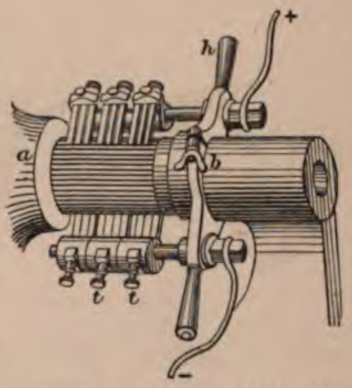

Fig. 50.—Details of the Multiple Brush Yoke, or Rocker.

In the case of large dynamos a single pair of brushes is never depended upon. The collecting cylinder is made of considerable length, and two or more sets of brushes are used. Any pair or one of these may be removed or held off separately. In this way it is unnecessary to stop the dynamo to trim a brush, or smooth a rough collector. The multiple system has other advantages, which need not occupy us further here. Referring to Fig. 50, which represents a "three-pair" yoke, *a* is the end of the armature, *t t* the brush-set or tension screws, *h* the lever, and *b* a butterfly-nut used in tightening the collar.

*Typical Ring-Armature Dynamo dissected.*—Having now described the nature of the Gramme method of winding-ring armatures, it may prove useful to present a typical example of an armature completed and ready for running. This is depicted in Fig. 51, which represents a rather elongated or cylindrical ring, as distinguished from Fig. 47 (p. 124), which represented a shallow ring. The core is composed of iron washers separated by paper, a method of building now almost universal. It will be observed, on reference to the former figure, that the connection lugs between the termini of the coils and the collecting cylinder are of considerable length, and that the collecting cylinder is situated as close as possible to the plane of the ring itself. This latter condition allows of a very short shaft being used, with the advantage of its being correspondingly stiff. The armature is secured with several bands of steel or brass wire (the latter is deemed the better, but both are freely used by builders).

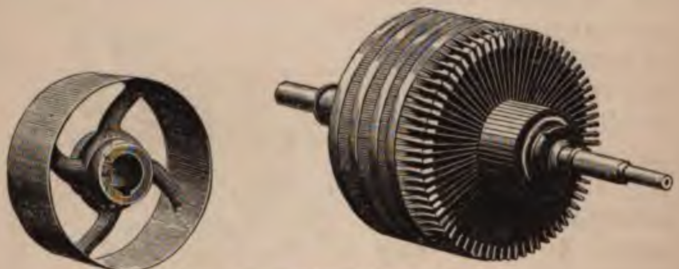

Fig. 51.—Complete Cylinder-Ring Armature.

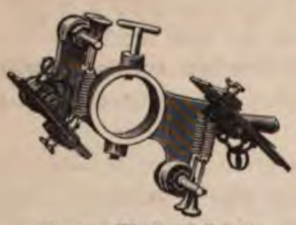

Fig. 52.—The Brush Rocker.

Fig. 52 represents the brush rocker, removed from its boss on the main casting. It is fitted with hold-on-and-off spring, by means of which the pressure of the brush upon the collecting surface may be maintained or the brush thrown back, and there retained by means of the second spring.

In Fig. 53 is shown the frame or base, field magnet and shaft bearings of the dynamo. This particular type will be seen to consist of two magnets with their poles combined, forming consequent poles, as in Gramme's original machine, but not excited by horizontal divided coils as in that pattern. The particular form here shown is also used by Mather and Platt in their smaller machines, with the exception that in their case the cores and coils are cylindrical. As here depicted the cores and coils are rectangular, with rounded corners, the substance of the cores being wrought iron and that of the pole pieces cast iron.

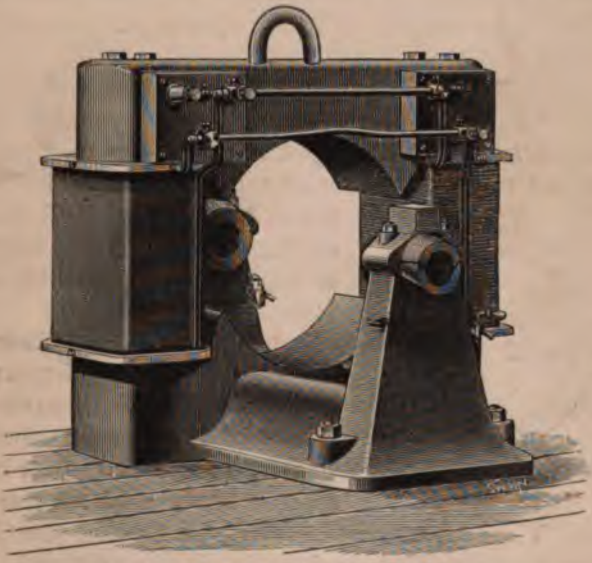

Fig. 53.—The Base, Bearings, and Field Magnet.

*Winding Ring for a Multipolar Field.*—In the ordinary Gramme ring all the bobbins are connected together, forming practically an endless helix. Connection is then made between each pair of coils and each bar of the collector. This method of connecting is only adapted to the case in which the ring is set in an ordinary two-pole field. Of late there has been a tendency to bring the principle of the ring armature into the construction of multipolar machines for alternating and continuous current dynamos, and this construction entails different systems of connecting the coils.

The coils of the ring are arranged as before, but *connections are established between those coils that arrive simultaneously at equal potential.* Suppose that, instead of two poles, the magnets take the form of four poles, distributed equally in the circle, those coils that happen to be 180° apart will at the same instant arrive at equal potential, and those two coils must be connected together, as in Fig. 54, when the terminals *a a'* would be connected to diametrically opposite collector bars, and so on throughout the circuit. The connections from the 'tween-coil junctions to the collector-plates are maintained as before. The brushes bear upon the collector at a distance 90° apart. This method is due to Mr. Mordey, who devised it for the improved Schuckert machine with four poles. It is especially adapted for dynamos intended to yield moderate potential. For armatures of higher potential Professor Perry devised a method of cross-connecting applicable to rings having an odd number of ils only. In this case the sectional coils are not

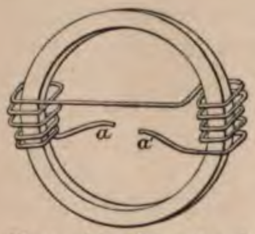

Fig. 54.—Cross Connection of Opposite Coils.

connected in series, as in the Gramme armature. Each section is connected as follows:—Its commencing end is connected to the collector-bar nearest to it. Its finishing end is connected across to the commencing end of the diametrically opposite coil, or to that coil which happens to be most nearly in that position. The same end of the latter coil is connected as before to the collector-bar nearest to it, and so on around the circle. As the armature is intended for a four-pole field, the collector brushes bear at points 90° apart as in the former case. This arrangement by cross-connection is similar to Gramme's, inasmuch as it yields the E.M.F. of half the coils at the brushes.

*Multipolar Windings.*—Multipolar dynamos are coming into extensive use, especially for central station lighting. They have many advantages to offer. While they are only generally adapted for comparatively low tension working and large currents, they may be driven at a slow speed, and have other advantages. The ring windings appear to be most in favour for these dynamos. The core is generally of the cylinder-ring shape, and the coils are frequently arranged alternately with Pacinotti projections. But armatures somewhat of the Brush pattern, or even more disc-like, are in considerable favour. Fig. 55 is a diagram of a four-pole cylinder armature as used in central station machines. It has four brushes, opposite brushes being of the same sign. The opposite brushes are in parallel. The coils *c c* take various forms. They are joined in series and again in multiple to the segment, as at *a a*. A somewhat similar winding has been used in the Gulcher machines.

Fig. 56 is similar to the above, with coils coupled in four parallels Opposite coils of the same potential are, however, coupled together, so that only two brushes are necessary. This method has been used in the Victoria machines. Several other methods of cross-connection have been devised; they all aim at reducing the number of brushes.

*Square Section Wire for Armature Winding.*—In order to economise space, it is a very general practice to wind rings and drums with wire of square section. By this means the space can be more fully occupied, and the distance between the core and field magnet faces diminished without a corresponding loss in copper conductivity. The use of square wire is therefore on the increase for this purpose.

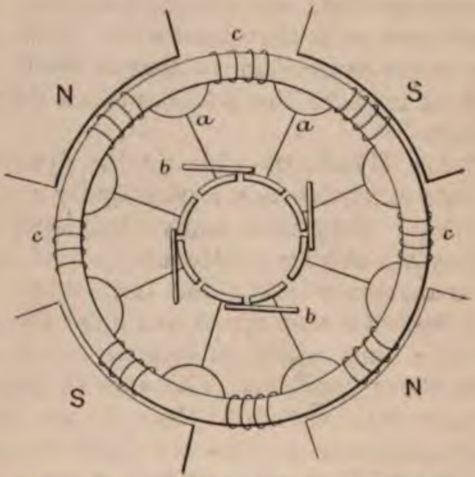

Fig. 55.—Windings of Multipolar Ring—Four Brushes.

*Cylinder Ring Winding.*—When the ring core is of extra depth it assumes the cylindrical form, and the term "cylinder ring" has been reserved for it in order to distinguish such armatures from drum armatures. These latter they closely resemble, except in the winding, which is quite different. Many electricians object to this form of the ring, urging, as they do, and not without reason, that the interior portion of the winding is to a certain extent idle, and adds only

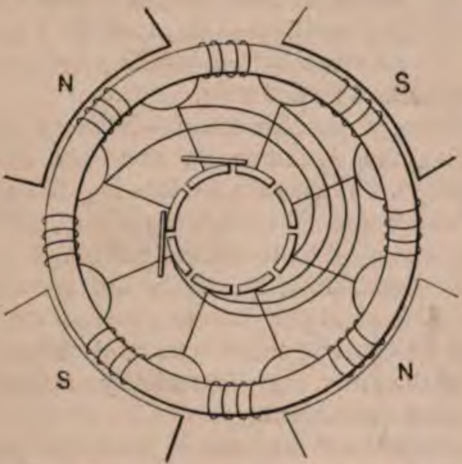

Fig. 56.—Windings of Multipolar Ring—Two Brushes.

to the resistance. With a powerful magnetic field, this need not be the case. It is possible to bring the core up to such a condition of saturation—over 16,000 lines per square centimetre—that the interior windings play an important part in the total output.

Cylinder-ring cores (Fig. 42, p. 109) are now almost invariably built up of thin iron discs. These are separated by paper in the usual way, and bound together in the required depth with insulated bolts. The fitting of such cores to run truly balanced is always a somewhat difficult matter. The centre of the disc is stamped out to a sufficient diameter to provide space for the shaft and windings. Radial arms, or what is more usual, a gun-metal star-wheel, keyed upon the shaft, engages in slots cut in the interior of the ring. A sectional view form of one of these driving appliances is given in Fig. 57. In all cases before winding the core is carefully *balanced* and turned true.

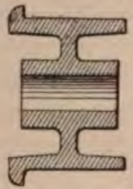
Fig. 57.—Section of Driving "Spider."

*Fan Spokes of the Star-wheel.*—In some of the recently designed dynamos an excellent device has been adopted. It consists in forming the spokes or arms of the "spider" or driving-wheel, with a *twist.* This is so arranged as to draw air through the centre of the core continuously, while the armature is in motion. It is thus possible to allow an armature so furnished to evolve greater heat and show a greater current, with safety, than one wholly enclosed, or not cooled by an air current.

As in the case of wire cores, the cylinder is coated with bitumen or japan. It is insulated further with wrappings of linen, varnished. The winding is greatly facilitated by the insertion of box-wood wedges in the core, marking the divisions for the sections. Slots are cut for these at either end at regular distances apart. It is, however, becoming more common to employ extra heavy end-plates of iron or brass with divisions cast on them.

The wire generally employed in winding cylinder rings is not round. It is more frequently of *nearly* rectangular section, being slightly of V form. This section is of great advantage in packing the wire in the interior of the ring. It will be clear that if it be required to wind the conductor closely covering the exterior of the ring in a *single* layer, the interior, being of smaller diameter, will probably be covered by *two* layers, and so on in proportion. Some makers employ thick conductors for the exterior windings, and thinner wire for the interior. This involves jointing, which is always objectionable. A good deal of skill is requisite in arranging the conductor to the best advantage, especially in maintaining its proper position in the interior.

*Driving Horns, &c.*—When the ring is very deep, cylindrically, a considerable length of wire lies without support along its length, exteriorly. It is usual in this case to provide wooden plugs or stops between the coils at regular intervals. These, in conjunction with the final circular binding wires, arranged in three or more bands, suffice to give the requisite stiffness to the exterior coilings. In some of the later dynamos the wooden wedges formerly employed at the ends of the core have been dispensed with, and radial teeth or gaps cut in the core plates instead. But this idea has been carried much further, and the whole length of the core has been scored up by longitudinal slots, wide enough to receive the conductors. Still more lately Mr. Crompton adopted the plan of threading the conductors through longitudinal holes running near the surface around the periphery. The effect of this is to bring the conductor within the core, and it is possible by these means to run the armature extremely close to the field-magnet faces. This has the effect of greatly reducing the resistance of the air gap, and a possible saving of the energy of magnetic excitation is effected.

In cylinder-ring machines intended for incandescent lighting direct, the electromotive force required need seldom be higher than 110 volts. It is found that at a moderate speed this E.M.F. can be developed by even a single layer of conductors upon the armature. For example, in an armature of one of Crompton's incandescent lighting dynamos the windings consist of 120 turns, every third turn being brought down and connected to a collector having 40 segments. The wire lies one deep upon the exterior and two deep upon the interior. The three turns constitute sectional coils with three turns in series. The conductor employed in the armature mentioned is of nearly rectangular sections, cotton covered, and further insulated by the insertion of strips of vulcanised fibre between the coils.

Ventilation of the cores is not always necessary. But cooling gaps are frequently provided in cylinder ring cores, by the insertion of divisions of narrow width at intervals of two or three inches. The divisions consist usually of radial pieces. In Crompton's armature they are ⅛-inch wide and occur every two inches of the length.

*Manipulation of Heavy Conductors.*—Conductors for cylinder-ring armatures are frequently of large section and low resistance (for dynamos of 100 volts and under). One method of manipulating these so as to reduce the jointing to a minimum is to bend the requisite turn-lengths in the form of a long, narrow ⊃, and to afterwards connect them in pairs or threes at the open end. In order to gain space the wire is sometimes drawn of oblong section, and the interior half of the loop is twisted at right angles to the exterior half, thus providing a narrower but deeper conductor on the interior than on the exterior. In one of Mr. Crompton's machines with grooved armature core, the completed armature was 28 inches in length and 12 inches in diameter, radial depth of core discs 23 inches, windings, 69 turns of copper ribbon, oblong section, cores of field-magnets, 3 feet 6 inches in length, 24 inches wide, 43 inches thick, with about 24,000 ampère turns magnetizing coils. At a speed of 440 revolutions per minute, the current was 229 ampères at 110 volts at terminals. In this armature there was one turn on each coil, therefore each turn was connected direct to each collector section. But the turns as a whole formed an endless coil, the section of copper being rather over a square centimetre.

The necessity to provide an adequate magnetic field for cylinder-ring dynamos has given rise to several devices for interior magnetic poles as well as exterior poles. It does not appear, however, that any one of these has proved itself a success. It will at once be discerned that as soon as we depart from the peripheral (Gramme) or face (Brush) excitation of a ring, and seek to complicate matters by additional poles, the armature becomes of a different character. It must be of larger diameter; the magnetic circuit is of much greater length (regarded from the old standpoint) and the windings must necessarily be modified to suit the new conditions.

*Ring Armature with Open Coil.*—In one or two special forms of machine, intended for high E.M.F. and arc lighting, a different arrangement of the coils is adopted. Mr. Brush appears to have been the first to employ the method of open coil working. As we have seen in the ordinary ring, the series of coils formed a closed circuit, but with outlets at the collector between each pair. The disadvantage of this arrangement is that the coils not actually feeding the circuit—*i.e.*, the inactive coils—still carry through them the whole work of the armature. The conception of open coil winding consists in the cutting out of these coils, leaving only in the circuit those coils actually contributing to the resulting current. This result can be obtained in any ring armature by a system of cross connection and by providing collecting slips for each complete circuit or pair of coils. Thus in Brush's open coil armature the inner end of each sectional coil is soldered to the inner end of that diametrically opposite. But there is no connection between adjacent coils.

In this respect the open coil arrangement is different from all other methods of winding-rings. The free extremities of the two opposite coils are then carried to two diametrically opposite plates of the collector or commutator. Each pair of coils may be said to have its own collector, consisting of two parts.

In a machine having eight coils wound upon the ring, there are four pairs of coils. The collector consists of two divided cylinders, each forming four separate insulated parts. Every pair of divisions is connected to a pair of coils. As there are two separate collectors, each consisting of four plates, two sets of brushes—one to each collector—are required. The effect of this arrangement is that *the pairs of coils are only admitted into the working circuit during their period of best action.* As soon as they cease to evolve a current, or in other words, pass out of the field, they are cut out of the working circuit, but at the instant that one pair is cut out the succeeding pair is cut in. Obviously a collector composed of four pairs, or right sections, and of the ordinary shape would not meet the requirements of this case. The period of contact, for instance, between brush and segment would only be the eighth part of a circle—*i.e.*, 45°—and there are other considerations to be met in the working of the particular armature under discussion. The peculiar form of the Brush collector has, however, been so fully described by other writers that we cannot here enter upon a more detailed examination. We are chiefly concerned with the method of connecting in the ring itself, and as this merely consists in putting the diametrically opposite coils in series with one another, instead of establishing a series arrangement all round the circle, no difficulty is likely to be met in mentally working out the result.

The Brush armature coils are wound in "pockets," or double recessions of the ring. The core (Fig. 44, p. 110) is thus not wholly overwound with turns as in most ring armatures. The coils are of considerable size and breadth, and only eight of them are wound upon the ordinary Brush armature. The larger armatures, intended for sixty lights (arcs), have twelve of these coils.

In the smaller machine the ring is 20 inches in diameter. The "pockets" before winding, are carefully covered with shellaced linen. The bobbins are necessarily wound by hand. The wire is in the first instance arranged upon a shuttle. Each bobbin consists of 900 feet of cotton-covered copper wire of a gauge of wire closely approximating to No. 14 standard wire gauge (diameter ·092 inches, sectional area, square inches ·0050; square mm. 3·242). The winding is carried out as compactly as possible with frequent divisions of varnished linen between the layers. All the coils are wound in a right-handed direction. They are coupled in opposite pairs as before explained.

*Spherical Armature.*—One more instance of open coil winding deserves mention. The spherical armature of the Thomson-Houston machine is absolutely unique both in its design and in its winding. The core has already been spoken of (Chap. VIII.). The coils are three in number, but they are so curiously combined that they may be regarded as forming one coil.

Into the surface of the core are driven wooden pegs to facilitate the winding. The core is then carefully covered by an insulator. Three wires are taken, and their extremities connected together, and the whole carefully insulated. Commencing near the axis of the core, the winding of the three wires is taken in turns by sections. Half of the first wire is wound around the core. This is carried out in the form of a wide, flat coil. Half of the second coil is wound in the same way at an angle of 120° with the first. The third coil is then wound at a still further angle of 120°. Then the remainder of the second wire is wound on, and finally the latter half of the first coil. All the ends finish off near the axis upon the side of the core opposite to the commencement. The free extremities are insulated and carried through a hole drilled longitudinally through the shaft, and so carried out to the collector. The object of this curious winding is to give the three coils equal distances from the iron core, and their arrangement at angles of 120° is intended to distribute the turns all over the effective area of the core. The windings are secured by bands of steel wire, as in other armatures.

The collector consists of three parts only, to which the three-coil extremities are connected. Two pairs of brushes are employed, the individual brushes of each pair being about 90° apart; but the pairs are situated as usual diametrically opposite. We cannot in this chapter follow the reactions, but the effect of this arrangement is to cut out the sections of the coil that are idle, and to admit those that are active, as in Brush's armature. The field-magnet poles intended to receive the spherical armature are of cup form, and embrace between them two-thirds of its entire surface, as depicted in Fig. 27, p. 87. In the ordinary sized dynamo the armature complete is $23\frac{1}{8}$ inches in diameter, and the gauge of wire used in winding, ·081 inches. The armature resistance is 10·5 ohms.

# CHAPTER XI.

## *DRUM ARMATURE WINDING.*

THE cylindrical armatures over-wound in the direction of their axis are generally known in England as *drum* armatures. There is this essential difference between them and the cylinder-ring armatures that, while the ring cylinder remains a ring and is wound with coils encircling the sides of the ring, the drum armature core may be regarded as a solid cylinder, the coils being formed by passing the conductor completely around it axially.

As we have already observed (p. 105), the drum core may either consist of a laminated solid cylinder, or it may take the form of a hollow cylinder or tube. The former plan is adopted by Edison and many others; the latter was first introduced by Alteneck in the famous Siemens drum armature. There is one point of similarity between drum armatures and the ring armatures already considered: drum winding usually takes the form of a closed coil, and generally forming a complete circuit from end to end. The varieties in winding refer chiefly to the connections that are established with the collector, and to cross connections between the coils.

All the varieties of drum armature have sprung from the original shuttle armature of Siemens (1856,

p. 11). The great objection to this form was that it evolved not a continuous current but a series of impulses. This was due to the fact that the winding consisted of a single coil or "loop" (p. 93), and that the sides of this passed alternately into and out of the magnetic field. The current therefore consisted (if not commuted) of a series of waves, alternately negative and positive. The waves were not rectified by commutation, although determined by one sign.

The improvements that have been effected consist simply in increasing the number of loops, and in so distributing these around the core that one loop at least is to be found at any instant of the revolution in the position of maximum effect, while some other loop occupies the zero position. By these means the waves are so "overlapped" or combined that they form practically a continuous current.

Drum armature cores have already been spoken of (p. 105). The same principle, that of effecting continuity in the conductor, has been observed in the core. While the original core consisted of an elongated electro-magnet, with poles that might have been regarded as salient, the modern core is a continuous cylinder. Its magnetization involves no reversals, or discontinuity of the magnetism. On the other hand there is a *continuous displacement* of the polarity; and if the core magnetically shows little "reluctance," the displacement, even under a high rate of revolution, is practically determined upon a line parallel to the lines of force crossing the field.

It is convenient, in speaking of drum armature windings, to regard the individual coils as loops, the two sides of each of which occupy diametrically opposite positions, or nearly so, upon the cylindrical core. Nine-tenths of the best drum armatures are wound upon this plan. Again, by far the larger proportion have their coils so connected together that they form from end to end a continuous elongated bobbin—in this respect there is a strong similarity between drum winding and ordinary closed coil ring winding.

Two methods of winding were tried upon the Siemens armatures. The first (invented by Alteneck) was unsymmetrical, and, to some extent, disadvantageous. It was abandoned in favour of a symmetrical winding known as the new Siemens winding, which, in turn, has to a great extent been superseded by a symmetrical method suggested by Dr. Frölich.

*Diagrammatic Views of Cylinder or Drum Windings.*—Since it has been found practically impossible to represent the course of the windings in a drum armature by an intelligible picture in perspective, the method of exhibiting it diagrammatically has been adopted by most writers. This has many advantages, but it leaves a good deal to the imagination. If, however, the reader takes the pains to follow the simple explanation given below, he will have no difficulty in discovering the advantages of

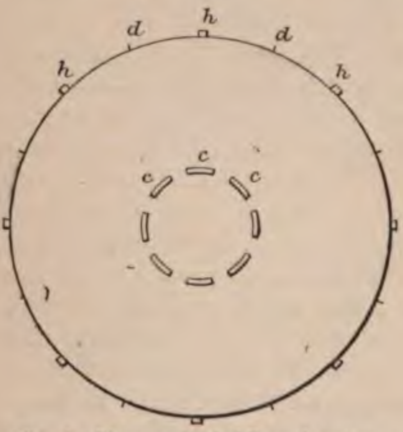

Fig. 58.—Diagram of end of Drum Armature.

the diagrammatic method. Fig. 58 represents the collector end of the armature, *c c c* being the bars; *h h* are driving horns enclosing spaces in which two or more half-coils are wound; *d d* are divisions between each pair of half-coils.

In all the diagrams here given the observer is supposed to be looking at that end of the drum armature at which the collector (commutator) is situated. Therefore, the *length* of the armature lying out of view may be neglected, and it serves the purpose to imagine the windings to be arranged simply upon a disc. Thus a bold line upon the face of the diagram, and its continuation as a dotted line, is intended to represent the visible wire and its invisible *continuation across the far* (or pulley) *end* of the armature. Thus in Fig. 59, which is of Edison's method of winding, the course of the wires from the commutator bars *along* the armature core and *across* the far end is very easily discerned.

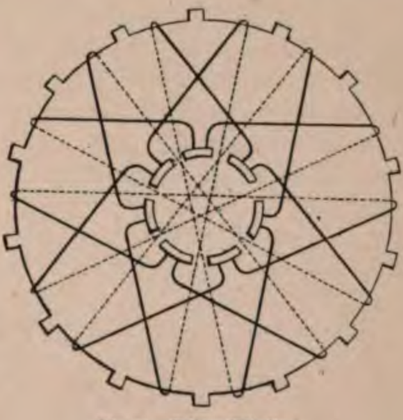

Fig. 59.—Edison Winding.

*Drum Windings in General Use.*—All the windings in use are modifications of the Alteneck winding, Fig. 60. They may be regarded as including every practicable method, and are known by the names of their inventors. The Frölich is a symmetrical alternate winding. The Edison is the Alteneck winding applied to an odd number of coils. The Weston is the Alteneck winding with the coils split up and distributed symmetrically. The Breguet is a rather irregular Alteneck winding. The Hering is the split-coil method applied to the Frölich winding.

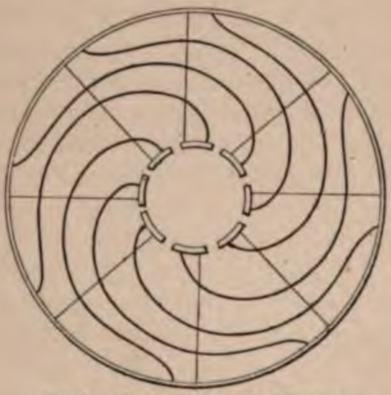

Fig. 60.—Siemens (Alteneck) Winding.

Referring to Fig. 61, if the end of a coil be fastened to a collector bar and the wire wound over the drum in the direction of *a*, and back over the far end and lower side, as shown by the dotted line, to *s*, the winding will be the Siemens or Alteneck. If the winding take the course *a f* the winding will be the Frölich. If it take the course *a b* it will be the Breguet winding.

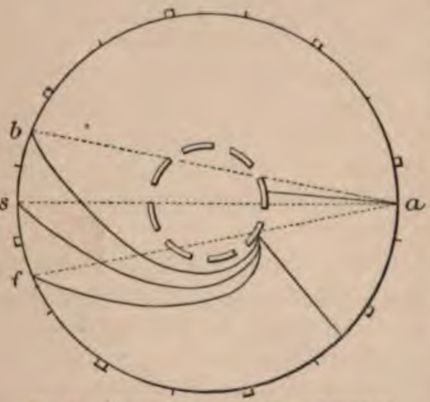

Fig. 61.—Diagram of various Drum Armature Windings.

In any one of these cases the coil is completed by bringing its finishing end back to the second collector plate, as represented.

*Dividing the Coils.*—Owing to the fact that each *turn* of the wire wound upon the drum occupies two lines upon its surface at diametrically opposite positions, it is clear that if the core be closely over-wound while it is gradually being turned, it will be found completely covered by wire while it has described but half a revolution. Thus, if there be eight coil spaces or divisions and sixteen collector bars, if the coiling proceed closely, and a connection taken to the collector at each coil space, the drum will be completely covered by wire, and only eight collector divisions will be allotted to coils. This is the general Siemens or Alteneck system. Another set of coils is then wound upon the top of the first, by which the eight remaining collector bars are appropriated.

This plan has the disadvantage that the under coils have both less surface velocity and length of circuit in the field than the upper coils, so that the armature may be regarded as out of balance electrically, the upper coils, occupying half the collector diametrically, having distinctly the advantage. The difficulty has in many cases been overcome by winding the coils in *alternate* sections, leaving blank sections for the remaining eight coils. This ensures that the coils shall have an equal mean radius and equal surface velocity. The method has been used in the winding of such Siemens machines as are provided with a moderate number of sections. When the number of sections (and collector bars) is great, some difficulties of winding are met with in carrying out the above method. Weston's method (windings shown in Fig.

62) undoubtedly meets all those difficulties in a practical way. The Weston armature is wound in channels formed in the core, as shown in Fig. 40 (p. 106). These channels are made to contain two coils (or two halves of opposite coils), but they are not superimposed. They are divided ingeniously, as represented in Fig. 63, where the white circles denote the wires of one half and the dark circles the wires of the other half. Their mean radius will thus be equal. Fig. 64 is a diagram of the Frölich winding. *h h* represent the driving horns, and the light and dark sections the going and returning halves of the eight coils. In winding an armature in this system it is necessary to observe that the "returning" wire falls into the proper channel, as there are always two paths open to it. Reference to Fig. 61 (p. 156) will make this clear, and will serve to explain why it is so easy to fall into either the Alteneck or Breguet winding.

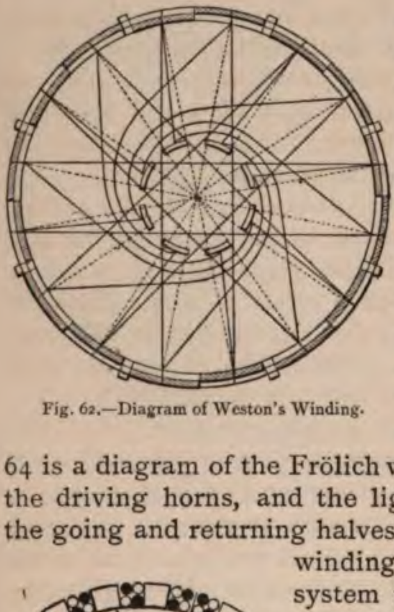

Fig. 62.—Diagram of Weston's Winding.

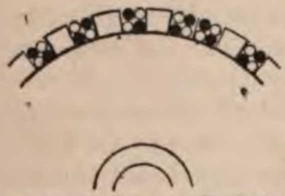

Fig. 63.—Section across Weston's Drum Armature.

Weston's winding, with divided coils, is depicted in Fig. 62. It is rather more complicated to carry out than either of the others, as two coils have to be manipulated at the same time, as already explained. It appears to be specially suitable to any method of double winding.

*Drum Armature with Frölich Windings.*—As an example of one of the latest improved armatures of this description, we may profitably describe the particular arrangement of the Frölich method of grouping. The core consists, as already described, of a large number of soft iron discs compressed into a cylindrical form between two brass flanges. These flanges have, cast upon their periphery, a series of regularly spaced oblong pins. These pins mark the divisions between the sectional windings. They are sufficiently high to stand to the level of the windings when complete, and serve also as driving horns for the coils.

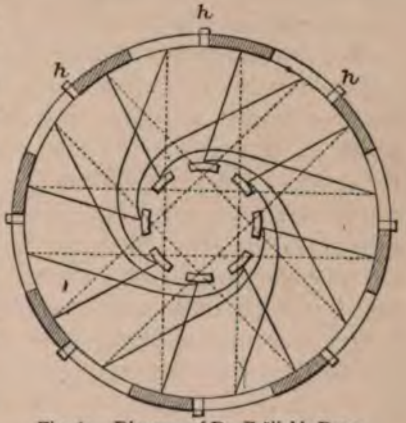

Fig. 64.—Diagram of Dr. Frölich's Drum Winding.

When the armature is very long a corresponding set of driving pins is inserted in the middle of the core. These are preferably projections from a malleable cast disc. Care is taken to round off every sharp corner in the course of the windings. The preliminary insulation is commenced by coating every part of the core and flanges with japan varnish. When this is dry the whole surface of the drum, including the driving pins (which are insulated separately), is covered with a layer of stout linen, varnished with shellac; or the excellent method described at p. 125 is employed. This is done as smoothly as possible, so as to economise space.

The windings are arranged in two layers, in four, eight, sixteen, or thirty-two sections. There are as many sections as there are collector bars. Sixteen sections is a very common number. Siemens' first machines had either eight or sixteen. It is to be particularly noted that the windings pass entirely over the drum in a lengthwise direction. They pass up and down over the ends, and in this way form oblong loops of a certain number of turns each. In describing the winding it is convenient to suppose the collector cylinder in position upon the shaft, and to speak of the windings numerically, as one, two, three, &c. The wire is generally (in the most improved armatures) of a rectangular section. It is usually double cotton-covered, and this insulation is often strengthened by running the wire through a bath of shellac or other varnish as it is wound into position. Strips of vulcanised fibre ("fibrate") or of Willesden paper are made of a three-sided rectangular shape, and these are placed between each pair of driving pins in order to separate the wire from them sufficiently.

Let us suppose the length of wire for one loop or coil to be taken. Its commencing end is connected to No. 1 bar of the collector. It is then wound upon the drum (in four, eight, or sixteen turns, according to the size of the latter, and the E.M.F. required), entirely filling the space between the first two lines of driving pins. In coiling the wire over a drum armature it should be noticed that as the shaft, passing lengthwise through it, is necessarily in the direct path of the coilings, these latter must be divided into two portions, one half of the coil taking the right hand and the other half the left. Let us suppose that the first coil has been completed, forming a single layer of wire of, say, eight turns around the core. Its finishing extremity will be connected to the second bar of the collector. From the second bar also will commence the second section of coiling But the winding of the second section does not in practice succeed that of the first section. On the contrary, in order to equalise the potentials, and preserve the insulation, the next coil to be wound is that diametrically opposite (*i.e.* No. 9). This section commences by being connected to No. 9 collector bar, and it is coiled compactly *on the top of that already wound*, the drum being given half a revolution prior to commencing this coil. Between the two sections or layers a band of vulcanised fibre is interposed. The finishing extremity of the No. 9 section is connected to No. 10 collector bar. Section No. 2 is now started by connection to No. 2 collector bar, or—which is the same thing—the finishing end of No. 1 section. This is coiled in the channel between the first section and the third row of driving pins, and its finishing end is connected to No. 3 collector bar. Then follows insulation, and the overwinding of No. 10 section, the commencement of which is connected to No. 10 collector bar (or to the finishing end of No. 9 section).

The course of the wire in respect to its path upon the core will be rendered clearer by an inspection of Fig. 65, in which, however, only two portions of coils at right angles to each other are shown. The collector, *c*, is also depicted as separated by some distance from the core, in order to render the arrangement clearer. In practice the collector is kept as close to the core, *d*, as circumstances permit. The connectors, *s s*, are attached as already explained.*

Insulation must be very particularly looked after at those points at the ends of the armature where the wires of different sections cross. Some armature winders adopt the precaution of interposing a disc of vulcanised fibre between each two sections at either end. Others adopt the plan of winding an additional covering of varnished tape upon the wire where it crosses the ends. When the sections are composed of fine wire in a large number of turns—the equivalent of high electromotive force—special care is requisite in thoroughly insulating every part of the windings. But a great deal of useful space may be needlessly sacrificed in this way if the separations are not intelligently effected. It is only necessary to insert extra insulation between those sections that simultaneously arrive at great *differences* of potential.

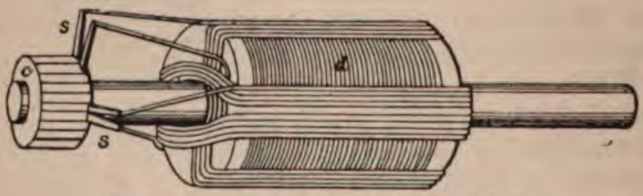

Fig. 65.—Course of the Conductor in a Drum Winding.

Although we have supposed, for the sake of illustration, that in winding the drum armature the collector is required, yet in practice this is dispensed with. The termination of each section is practically made one with the beginning of the next, and the junction is connected as one to the collector lug. In the best constructed dynamos the radial arms, extending from the collector plates to the periphery of the armature, are composed of thick bars of gun metal. They are screwed by means of projecting foot-pieces to the bars, and their free extremities are pierced with apertures and fitted with set screws for receiving the coil terminations. In the early dynamos the whole of this work was effected by soldering. Apart from its inferior stability the latter method presented the disadvantage that in the event of repairs being required the parts were not readily separated.

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* An excellent isometrical diagram of the ordinary drum conductors was given by Mr. Weymouth in the *Electrician*, vol xxiv., p. 274.

*Windings for High and Low Tension.*—The electromotive force is nearly proportional to the *number of turns* in each section. The number of convolutions that can be wound in a given space will depend upon the section of the wire. The finest possible wire would thus yield the highest possible electromotive force, and conversely, the minimum electromotive force would result if only one turn of the thickest possible conductor were employed in each section. Between these two extremes there is a wide field for ingenious combinations of windings to meet the requirements of different cases. Thus, a dynamo intended to run arc lamps in series—the most economical plan—must evolve volts in proportion to the number of lamps, and as a single lamp requires not less than 30 or 40 volts, the resistance of a number calls for a very high electromotive force. In this case the section must consist of a large number of turns. If the machine be intended for incandescent lighting, a "voltage" of about 100 will be sufficient. The section in this case would consist of a moderate number of turns only, and those of a much thicker wire. Further, if a very low "voltage" combined with a large current, as is required for electro-plating, be aimed at, the section might consist of one or two turns only. These remarks are not, however, intended as a guide to this important question. Many other things must be known, as the force of the magnetic field and the peripheral speed of the armature, together with the circuit resistance, before any one of these conditions could be even approximately determined.

*Testing for Short Circuits.*—During the progress ot winding drum armatures, it is essential to keep a watch upon the insulation of the wires. This becomes of still greater importance if the wire be fine in many turns. After each section is wound it should be tested for the following possible faults :—

(1) Short circuit to core of armature.
(2) Short circuit, or leakage, to any other section.
(3) Short circuit within itself.

The testing apparatus generally employed consists of a few cells of accumulators, or a bichromate battery to furnish the testing current, and a galvanometer for detecting purposes.

To ascertain short circuit to core, connect battery, galvanometer and core in series, and make contact (with a wire from the remaining pole of the battery) to the ends of the section it is desired to test. The smallest deflection of the galvanometer will indicate a leakage.

Short circuit, or leakage between section and section, is much more apt to occur. Before testing for this fault disconnect all sections from each other.

Connect, as before, the various sections, each in turn, in series with the battery and galvanometer, and make contact with each remaining one of the sections. A deflection will indicate the sections that touch metallically in crossing In order to obviate the inconveniences of unwinding several sections in case of a fault, this method of testing should be in constant requisition during the whole operation of winding the armature. In this way an incipient fault is located before other sections have covered it up. The third fault can only be detected by measuring the resistance of the section; any diminution of this would, of course, indicate a cross between some two of its turns.

*Various Devices for Neutralising Eddy Currents in Drum Armatures.*—In the armature windings of dynamos intended for the production of large currents various devices are resorted to for the purpose of preventing the waste of eddy currents. Siemens, in some of the larger dynamos, employs varnished stranded cable, forced by drawing or compression into the required rectangular cross section.

More frequently the rectangular bar, required for one half-coil of the armature, is composed, in that shape, of wires. It is then taken and twisted through 180° at the middle. This has the effect of causing any current passing along one side to follow the twist and flow on the opposite side along the remaining half of the bar. Any eddy currents, therefore, coursing along the first half of the bar will meet opposing currents in the other half, after passing the twist. These two currents will, therefore, neutralise each other. After giving the bar the half-twist, it is again compressed by hydraulic power to the uniform rectangular section.

Still another way is to form the bar of ribbon copper, varnished. The ends are all soldered together. But this is not entirely satisfactory, because the connection at the extremities opens up a path for the current up one side of the bar and down the other. This may, however, be obviated by imparting a half-twist to the bar at the middle as before, and finally compressing it to the required form.

A considerable number of such devices have been patented. The aim in all of them is to find a method of perfectly neutralising eddies while preserving the essentially simple character of the plain bar.

Dr. Hopkinson resorts to the device of giving greater clearance between the *horns* of the field magnet and the armature, than obtains at the central line parallel to the lines of force in the field. It simply consists in turning the armature bore-hole in the field magnet a little too large, and in bringing the magnet faces as closely as possible to the armature's periphery. This forms a slightly *elliptical* chamber for the armature, and results in there being a greater space (or clearance) between armature and field magnet at the horns than elsewhere. But it is found that the eddies, in as far as they refer to the magnet, occur in greatest strength at the trailing or rear horns in the direction of motion, and a slight additional clearance there has the effect of rendering the field more symmetrical in respect to the armature chamber.

*Heating of the Pole Pieces.* — In the running of dynamos the effects of the eddy currents can easily be traced. They principally go to heat the field magnet. While the magnet's horns at the entering side (in the direction of motion) are generally comparatively cool, the following horns are sometimes sufficiently heated to melt a stick of sealing-wax put in contact with them. The armature revolving, as it does, in air, is kept comparatively cool, but considerable loss can, nevertheless, be traced to faulty construction in the direction of non-lamination of the bars.

Laminated armature bars are generally insulated by a close wrapping of varnished tape. But it is quite practicable to employ such bars quite bare. In some of the best dynamos this method is followed. It then becomes comparatively easy to keep such bars cool. Bare conductors are generally socketed in snugs of insulative material projecting from the body of the armature. The external wrappings of steel wire around the whole of the armature are wound upon a sufficiently thick band of mica, so effectually separating the wire and the bars.

*Ventilation of the Armature.* — Coupled with the question of the disposal of wasteful eddies is that of ventilation, so that the heat due simply to normal resistance may be got rid of by the cooling effects of air. A great deal of trouble was experienced in this direction by early builders. Given a well-laminated conductor, and a current-density not too high, a moderate number of openings for the passage of air through the armature suffices. It does not appear, however, that in any dynamo yet built, and working at full load, its designer has been able to afford to dispense altogether with ventilating apertures.

*Turns in Multiple Arc in Armature.*—Armatures intended for low resistance work, as for incandescent lighting or for electro-metallurgy, are usually constructed so that their own resistance is inappreciable. This is effected by making each section essentially in the form of a copper bar, the area of which occupies the whole of the space available for each section. But the substitution of solid copper conductors of large cross section has been found to present, in practice, certain disadvantages (already alluded to under the head of "Eddy Currents," p. 103). The practice of lamination must, in short, be carried even into the conductors themselves. They consist, therefore, of a number of copper ribbons, slightly insulated from each other. In many cases the strap copper is merely varnished. In the larger dynamos it is covered with a single layer of cotton.

In addition to the electrical advantages of lamination, there are certain mechanical advantages. It is more easy to manipulate conductors subdivided, and to wind or bend them to the required form. But armatures that are wire-wound in many turns, may be converted into low resistance armatures, by the simple method of connecting the turns in multiple arc. Suppose a section having eight turns of wire. If it be desired to halve its resistance, that may be accomplished if the wires are connected across in four pairs. The resistance might be again halved by again cross-connecting the four pairs, having two turns only. To illustrate what is meant, suppose, in the first case, we were to solder a wire or short junction across the first two turns, these two would act as one turn only. Similarly, with the next two turns, and so on. If a wire were soldered across, touching all the wires, bringing them electrically together, the whole of the turns would act as one turn only. Any junctions made in this way, in practice must be very substantial, and the bridging wire must be of large cross-section. Many low-resistance armatures are cross-connected (wound in multiple arc), but it may be pointed out that the practice of dynamo builders is decidedly in favour of economising space by using, when possible, lightly separated copper strap. The desired end is thus secured without the waste of space inseparable from the employment of ordinary round insulated wire. In any case round wire is not so effective in a *given space* as square wire—a greater cross-section of the latter is easily obtained.

*Current Density in the Wires.*—It will be seen that the foregoing practical considerations bear strongly upon the question of sectional area and current. As the former is increased so may the latter be augmented. If we assume 2,000 ampères per square inch of sectional area to be a safe working current in a particular coil, we may maintain this density throughout any changes effected by connecting in multiple arc. In accordance with the law of Ohm, if a current of 50 ampères be safe in an armature section of eight turns, it may be augmented to 100 ampères if the wires be cross-connected so as to take but four turns. If the turns be again divided, and brought down to two, the current may with safety be 200 ampères, and so on.

*Depth of the Air Gap.*—The air gap through which the magnetic lines act consists of the distance between pole faces (of the field magnet) and peripheral surface of armature. The depth of wire upon the armature core is, therefore, a direct addition to the resistance of the air gap. It will thus be discovered that, in order to keep down the width of the air gap, the thinnest possible conductor and the least possible insulation should be employed. But other conditions must be considered. We must first have *turns* sufficient to develop the electromotive force required. Sectional area (which means thickness) must then be allowed to carry the current safely. But it is obvious that a mistake may well be made in providing *too great* a sectional area in the conductors. To a certain extent this would return us a certain percentage of advantage by reason of diminished armature resistance, but the loss due to increasing the air gap resistance needlessly, would more than counterbalance this, and a loss would result from having the conductors larger (deeper) than necessary. The precautions regarding current density refer, of course, to *heat* in the wires. If the armature be wound with only one layer, and ample ventilation is allowed, 2,000 ampères is a small current density. Many armatures are pushed far beyond this. There is, of course, a certain loss by reason of this heat; energy is being dissipated. But it is assumed that there is a greater gain than loss in reducing the depth of the conductors to a minimum for reasons stated above. On the other hand, however, when there are necessarily several layers, heat is not easily dissipated, and the current density must be kept as low as possible.

*"Dead" and "Active" Wire on the Armature.*—A certain proportion of the length of wire wound upon a drum armature is always inactive. It does not come within the influence of the field and generates no electromotive force. This dead wire occurs at the ends of the cylinder. It is a necessary evil in every dynamo. Some means must be provided to carry the current across the diameter of the core. The most ready method is to simply carry the conductor itself across, and this is done in all armatures wound

with wires or flexible cable. But in the case of larger armatures, when the conductors assume a more solid and less flexible form, this is impracticable. Half-circle segments, discs, and other devices are therefore employed, as exemplified in the construction of several dynamos described in these pages. Since the cross-diameter connections cannot be dispensed with, the builder's object must be to make them of as low a resistance as possible, so that very little energy is consumed in that direction.

The active wire is that upon the sides of the core. In this position it moves well within the influence of the field. Every inch of the active wire is, therefore, to be calculated upon in estimating the electromotive force per foot of the conductor. The percentage of active conductor to the total varies generally from 30 to 60 per cent. In many cases it may be shown that portions of the cross wires, usually considered inactive, participate in the production of electromotive force, but the effect is generally so small, being due to oblique or "leakage" magnetic lines from pole to pole, that it may be safely neglected.

The electromotive force in volts per yard of active conductor, varies with the intensity of the field and the speed. In some of the best dynamos yet built the mean intensity of the field in lines of force per square inch varies from 16,000 to 25,000. In the recent exhaustive tests of dynamos by the Franklin Institute, it was found that in an Edison dynamo, in which the field had a mean intensity of 25,000, the mean induction in volts per foot of conductor was 1·733—an extremely high induction. Reduced to a speed of one foot per second, it was ·0373 volt per foot. In low speed dynamos, with a moderately intense field, 1 volt per foot may be regarded as high, while from 1 to 1·5 volt per foot is not uncommon in high tension arc lighting dynamos. With a circumferential velocity of 3,000 feet per minute, some tests of dynamos in this country, showed that with a moderate intensity of field the Edison-Hopkinson machine had ·510 yard of conductor per volt evolved; the Crompton showed ·860; Kapp, ·970; and Thomson-Houston, 3·550.

*Circumferential Speed of Armature.*—The maximum peripheral velocity observed by good makers, may be taken as 3,000 feet per minute. This is very high; 1,500 feet per minute is much more common. In the recent Franklin Institute tests, the mean velocity of the Edison (large) machine was 46·5 feet per second; in the Weston (large) machine it was 37·4 feet per second.

*Lines of Force per Watt.*—The number of lines of force in the field per volt-ampère of output varies greatly. This may be regarded as the relative efficiency of the field. It may be said to vary from 5,000 in common dynamos to 10,000 in machines with wrought-iron magnets.

*Cross section of the Armature Conductor per Ampère.*—This is most usefully expressed in square mils. It varies greatly in different armatures. In those adapted for the rapid dissipation of heat only 400 square mils are generally allowed per ampère of current evolved. In closely wound armatures, where heat is apt to prove injurious, from 600 to 800 square mils per ampère are usually allowed.

*Percentage of the Diameter of Armature occupied by Windings.*—In the case of drum armatures this varies in different machines, from 8 to 12 per cent.

*Low Resistance Drum Armatures.*—Although we have seen that the resistance of an armature may be reduced to any required extent by the simple device of connecting its turns in multiple, yet that method has not found much favour in the building of very large machines. The construction of low-resistance armatures presents no difficulty in reference to that particular quality, *per se*, but other questions arise when large currents are to be carried by conductors of considerable cross-section in an armature. In the early Edison machines, the first of their kind devised for low tension electric lighting, solid bars of copper were used. Many other dynamo builders also constructed armatures having heavy square bars as conductors, and at that time the method was considered excellent. The discovery, however, that it was nearly impossible to keep such armatures cool, and that the chief cause of this was the generation of eddy currents in the bars, has changed the course of progress in that direction. There was not only the difficulty of heat to be dealt with—that was troublesome in frequently breaking down the insulation. It was soon discovered that this heat meant waste, and that the old-fashioned dynamos exhibited, under test, a very low efficiency.

The method of winding adopted by Edison in his incandescent lighting armatures is described by means of a diagram in the patent specification. This shows a symmetrical arrangement, as in the Alteneck method, but the number being an odd one it is difficult to understand that it could be worked in connection with brushes bearing upon the collector at diametral positions. In the earlier dynamos a multiple of seven was generally taken as the number of paths or sections of the armatures, up to forty-nine in the large machines used for street lighting in London. In those machines the conductors consisted of thick copper bars, except for the cross-connections at the ends. These were effected through a series of copper discs. Each disc had two projecting lugs, for purposes of connection to the bars and to the collector segments. The discs were carefully insulated from each other, and from the shaft.

Since the introduction of suitable insulated ribbon copper the solid bars have fallen, to a large extent, into disuse. Strap copper is more easily manipulated than bars, and it is unnecessary to adopt the expedient of disc cross connections at the ends of the core. Mr. Edison's aim in inventing the disc device appears to have been, according to the specification, the reducing of the resistance of that portion of the windings necessarily idle, and passing across the ends.

It may be pointed out, in reference to low resistance armatures, that their chief advantage in electric lighting by incandescence lies in the self-governing power they give the dynamo. Since the resistance of the armature is but a mere fraction of that of the external portion of the circuit (in many cases it is merely nominal) any increase or decrease in the external resistance will have but a nominal influence upon the armature. This is especially so if the latter be run in a field of great intensity. The latter should be so powerful that any self-induction of the armature is easily overcome. Such machines are generally shunt wound; and so perfect are they that in many cases it is unnecessary to employ compound winding of the magnets, or any regulating device exterior to the machine.

*Circumferential Speed of Drum Armatures.*—The maximum circumferential speed of drum armatures may be taken as approximately 3,000 feet per minute.

*Yards of Conductor per Volt of Electromotive Force.*—The length of electric conductor wound upon armatures for each volt in the total potential difference varies greatly. Mr. Kapp gives the following figures to exemplify this:—

| | |
|---|---|
| Edison-Hopkinson (Drum) | ·510 yards. |
| Crompton (Cylinder Ring) | ·860 ,, |
| Kapp (Drum) | ·970 ,, |
| Thomson-Houston (Sphere) | 3·550 ,, |

## Alternating Current Armatures.

The most important class of this type appears to be the disc dynamo. Many excellent machines have, however, been constructed for alternating currents having drum armatures. We may consider the disc armature first.

There is one leading feature in most of the machines of this kind—a multipolar field. This is essential in view of the necessary rapidity of the alternations. Since the currents are required to recur some hundreds of times in a second this can only be accomplished by increasing the number of poles between which the coils pass during one revolution. There are in many of these disc machines from twenty to fifty magnetic fields. When a single coil or section passes once around the circle it cuts the lines of force a proportionate number of times, and thus, by a comparatively slow period of revolution, a disc armature may give rise to a high rate of alternations.

The sectional windings of a disc armature generally assume the form of wire whirls, or snail-like spirals, or of narrow, disc-like coils. The course of the conductor in these disc coils almost invariably occurs in alternate directions in a series of coils, as represented in Fig. 66. This is essential in view of the fact that the magnetic field is also of an alternating nature. But in armatures of very low resistance the coil section is dispensed with altogether, the conductors merely forming radial bars or loops. The multipolar field is common to all of these.

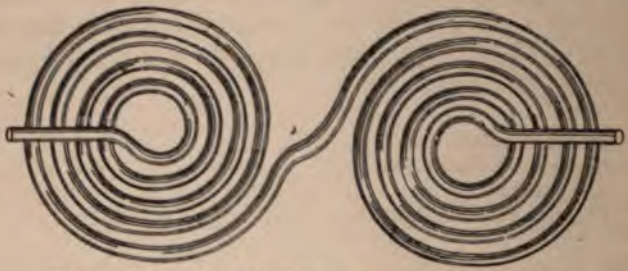

Fig. 66.—Right and Left-handed Arrangement of Alternator Coils.

*Iron-cored Bobbins*, mounted near the edge of a disc, belong to an early period of the history of the dynamo. They are at the present time superseded. But it may be of interest to inquire into the chief cause of their abandonment. Both in the alternating dynamos of Wilde and Siemens (the early experimental machines of the latter) iron proved troublesome on account of heat. In other words, the rapid or sudden reversals of polarity gave rise to a great deal of waste in the form of eddy currents. Even the device of lamination, although successful enough in cases where the magnetic changes were slower, was unsuccessful. But if we regard the magnetic field as a space across which lines of force are projected, and if we look upon the iron-cored form of armature as a means of filling the field with a body capable of conducting the lines of force across from one pole to the other, it is an easy transition of thought to the narrow magnetic field of Faraday's famous disc dynamo, and the abandonment of iron altogether. Faraday rotated a copper disc between two closely-approaching poles. We can obtain stronger effects by doing the same thing with a series of narrow coils.

Siemens' dynamo, built upon these lines, had no iron in the armature. The bobbins were attached to the arms of a "spider" of gun metal, rotating with the shaft. The coils were as narrow—disc-like—as possible. The magnetic field from pole to pole was as thin as practicable. This dynamo proved that by concentrating the field, and by narrowing our conductors to the required form, it was not only practicable, but advantageous to dispense with the inductive assistance of iron.

The construction of alternating armatures greatly simplifies the dynamo. The mere fact that iron is dispensed with means a great deal more than the bare fact implies. We have to deal only with conductors cutting a magnetic field: and, in our calculations, we have to deal only with the magnetic permeability of air and copper.

*Coil, Ribbon, and Loop Alternating Armatures.*—We are not dealing here with the construction of the dynamo as a whole; but it appears advisable to revert, for a moment, to the multipolar field of alternators. It consists, in nine machines out of ten, of two opposing crowns of poles, as already illustrated and explained (p. 87). Siemens' and Wilde's field consisted of two circular cast iron frames, set in a vertical plane. Projecting from the adjacent faces of these were two circles of iron cores, carrying exciting bobbins. The frames were set so close that only a narrow space separated the opposing poles. The latter were so connected that alternate polarities were presented, and in each it faced a S pole. Hitherto we have spoken of the field magnets as fixed, while motion was given to the armature. But an opposite arrangement is not unknown. Mr. Mordey, in his famous alternator, has shown that an inverse arrangement is not only practicable, but, as embodied in his machine, a considerable advantage.

If we take a coil wound in a particular direction, and pass it between the poles of a magnet a current in a certain direction will circulate in it. If we now reverse the polarity of the magnet, so that the pole that was N becomes S, and again pass the coil, an opposite current will be exhibited. Hence, *in a multipolar field, with alternate poles the armature coils must be connected or wound in alternate directions*, otherwise the current in the first coil will nullify that in the second, and so on.

As the kind of alternating armature under discussion consists of a disc or its equivalent, carrying coils, it will be obvious that that arrangement presents peculiar facilities for working at either high or low electromotive force, and for varying the resistance to correspond.

1. If all the coils be of the finest wire, and if they be connected in series, as represented diagrammatically in Fig. 67, the E.M.F. will be the highest possible.

2. If the coils consist each of but one turn, and hat of the thickest conductor, and they are connected

in multiple arc, they will act as one coil, and the E.M.F. will be a minimum, while the resistance will

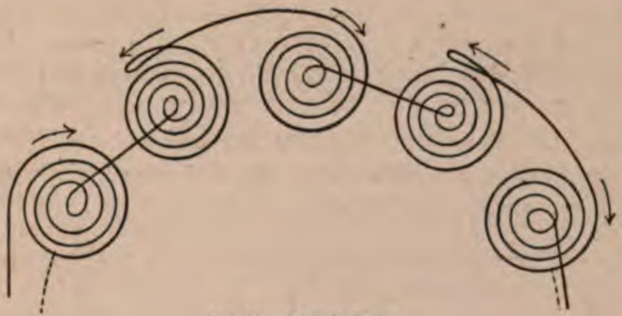

Fig. 67.—Coils in Series

also be the lowest possible, or, as in Fig. 68, when each coil consists of several turns.

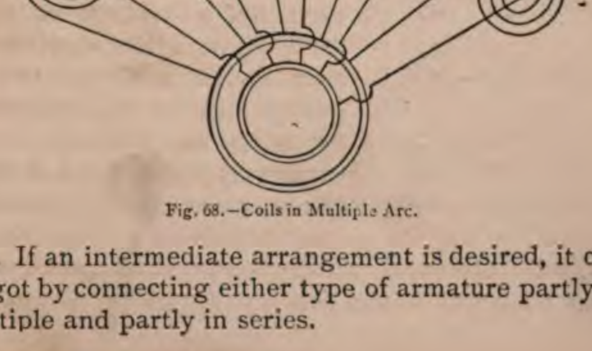

Fig. 68.—Coils in Multiple Arc.

3. If an intermediate arrangement is desired, it can be got by connecting either type of armature partly in multiple and partly in series.

The conditions under which the electromotive force can be varied are exactly similar to those appertaining to the arrangement or grouping of voltaic cells.

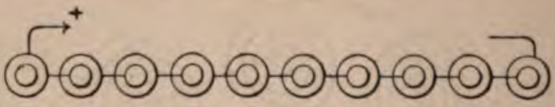

Fig. 69.—Coils or Cells in Series.

If, as in the diagram (Fig. 69) we connect the ten cells in series, we obtain the tension due to that number (*i.e.*, if the electromotive force of one cell be one volt it will, under the above conditions, be increased to ten volts for the combination). If, on the other hand, we desire only the electromotive force of one cell, but the current of ten, the grouping must be as in Fig. 70. If, for example, a voltage of 3 be desired, with the current of four elements, they must be grouped as in Fig. 71. Coil grouping is effected in the same way, each coil being regarded as having a given electromotive force.

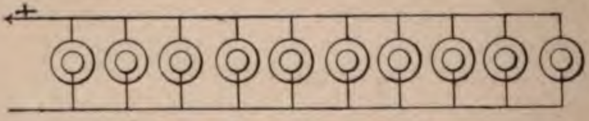

Fig. 70.—Coils or Cells in Multiple.

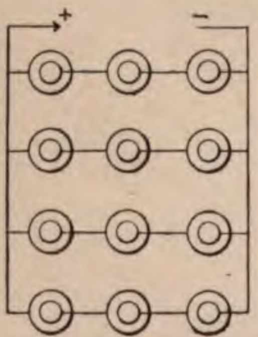

Fig. 71.—Intermediate Arrangement.

*The Coils.*—Siemens' coils consisted of ordinary insulated wire of round section wound upon wooden bobbins. The sides of the bobbins were pierced for ventilation. For arc lighting, by alternating currents, the whole armature was connected in series. The field was excited by a separate continuous current machine. For low resistance working the same machine is either connected partly in series and partly in multiple, or is wound with thick copper ribbon, and connected in series.

Ferranti's alternator, at the suggestion of Sir Wm. Thomson, was at first furnished with an armature composed of a thick copper bar, bent into eight loops, radial from the centre. It has been likened to a flower of eight petals. Here we have no coils, but we have conductors cutting lines of magnetic force, which amounts to the same thing—a kind of divided Faraday disc. In this dynamo the poles of the field are elongated—pear-shaped—in the radial direction, so as to influence as great a radial depth of the conductor as possible. The patent specification shows the eight loops as connected in a single circuit. Later on the solar conductor was found to give trouble from heating due to eddy currents. Lamination was resorted to with much success. As now constructed the armature is composed of copper strap, wound in thirty layers, all carefully insulated. But these compose three complete circuits of ten strips each. The circuits are connected in multiple. The insulation is so perfect that with copper strap $\frac{1}{2}$ inch in width the total width is only $\frac{5}{8}$ inch. The magnetic field is therefore rather less than $\frac{3}{4}$ inch in width. The armature windings are carried by a gun-metal star keyed to the shaft. The arms of the star are in two sets, between which the armature is mounted by the aid of cross-bolts. The ends of the armature conductor are led away to a pair of insulated gun-metal collecting rings, rotating with the shaft. Dynamos having armatures of this type, and with zig-zag conductors, are now comparatively common.

Mordey, as stated above, finding that an armature of this description had certain faults, took a heroic step, and reversed the arrangement. When an armature of the Ferranti type is running at a high rate of speed (the one under consideration was 30 inches in diameter, and moved at the rate of 1,400 revolutions per minute) certain axial undulations are very apt to show themselves. This is especially the case if there be not absolute uniformity in the tangential drag of the field. It is difficult to impart rigidity to a loop armature. Any wavy tendency in the axial line would necessitate greater clearance between armature and poles, and this implies a greater than proportionate loss of effect. Mr. Mordey conceived the idea of making this type of armature a fixture. To effect that purpose necessitated a different arrangement of the coils, and it implied the revolution of the magnetic field. With the latter we are not at present concerned (see p. 88), but the coiling claims particular attention. The armature consists of a rigid ring of gun-metal, to the interior of which are attached the coils. These are eighteen in number, of the form of a V, with a rounded point. The coils compose a circle. They consist of copper strap, wound upon porcelain cores of the required form. In this case the conductors are in the form of individual coils, which are connected together in series or multiple, as may be required. Being laminated, there is little tendency to heating.

*Drum Alternator Armature.*—The coils in this case consist of conductors wound usually in the form of a long, narrow link, and laid upon the surface of an iron core in the form of a drum. The link-like coils are made as long as the drum, and are laid side by side, either upon insulating cores, or bound by clamps at the ends. In either case the radial depth of the hanks is made as small as possible in order to diminish the width of the air-and-copper gap. The field magnets are of an elongated type, having a length equal to that of the drum. The drum alternator takes several forms, which we cannot discuss here; but the dynamo lately brought out by the Westinghouse Company is a good example of this class of machine.

*Ring Alternator Armature.*—This type is too important to be passed over, although few examples of it are to be found. If a Gramme ring be so connected that its sections lead the current in opposite directions throughout, such a ring may be mounted in a multipolar field. The connections to the external circuit must, however, not resemble those in an ordinary ring. The sections may all be connected in series, and the terminals taken to a simple pair of collector rings rotating with the shaft, or they may be put in multiple in any arrangement that will develop the required E.M.F.

*Alternator Collectors.*—There are one or two machines in which the field magnets are excited by the current from the armature, but the application of this principle is becoming more and more rare. Mr. Wilde employed this device in his machine by diverting the currents from two or three of the armature bobbins to a separate *commutator*, the function of which was to impart to them a uniform direction. The currents from the remaining bobbins were passed direct to either a commutator or a simple collector, as the case might require, and utilised for external purposes.

But most alternating current dynamos are separately excited. A small continuous current dynamo is used for that purpose. It is sometimes attached to the shaft of the larger machine direct, and runs at the same rate of speed as in Mordey's alternator. Since the intensity of the magnetic field does not depend upon the work thrown upon the armature these machines are almost self-regulating, and are easily controlled. The collectors used for taking the current from the alternating armature consist simply of a pair of copper, gun-metal or phosphor-bronze rings. These are insulated from the shaft and from each other, They revolve with the shaft. The terminals of the

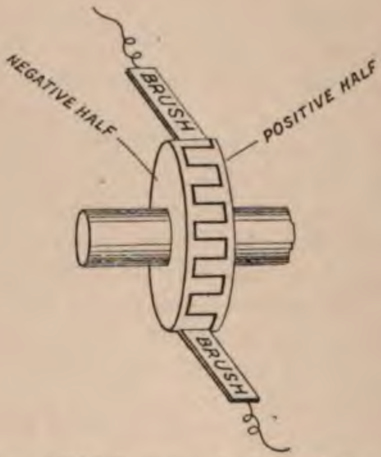

Fig. 72.—Wilde's Commutator for Alternating Currents.

external portion of the circuit consist of the usual pair of flexible metallic brushes.

Wilde's commutator, intended to give the whole or any part of the alternating currents a uniform direction, consisted of two cylinders of copper, cut in the form of crown wheels, the teeth of one cylinder fitted between the teeth of the other. They were insulated from each other, and from the shaft. There were an equal number of teeth and coils. A pair of brushes were used to collect the currents, one in advance of the other, the width of a tooth. It will be clear that upon the revolution of the commutator the brushes would press upon alternate teeth, or cylinders. The change from tooth to tooth took place at the instant of change of current direction in the coils. In this way the current in the brushes was determined in one direction. This arrangement is represented in Fig. 72. Another form of the alternating commutator consisted of an ordinary collecting cylinder, as used for continuous current dynamos. Every alternate bar was connected to one extremity of the armature coils, while the intervening set of bars were in like manner connected to the other extremity. In this way the brushes would exchange terminals as often as the currents in the coils were reversed.

*Machines without Collectors or Commutators.*—The collecting ring, or the commutator, is only required because the armature revolves. If the latter becomes a fixture, as in Mordey's machine, no collector is required in taking off the armature current. But in that case it is plain that as the field magnet revolves instead of the armature a pair of ring contacts will be required to pass the exciting current through the field magnet.

### Unipolar Dynamo.

The name "unipolar" has been applied to that class of experimental machines designed to work upon the principle of Faraday's disc. Few, if any, of this class of dynamo have proved successful. The necessity for collecting the currents from the periphery of the armature is one of the practical objections to this type. The very low electromotive force—seldom exceeding five volts—is another objection. The development of the "unipolar" dynamo has been so slow, and the results, so far, so unsatisfactory, that it cannot be regarded as having passed through the experimental stage.

## CHAPTER XII.

## *ECONOMIC DESIGN.*

BEFORE the scheme of a new dynamo can be laid out, certain conditions must be known.

(1) The *speed* or number of revolutions of the armature per minute. This will depend upon the nature of the proposed machine. If the dynamo be intended for ordinary purposes on land, a high rate of speed is permissible. The speed has a great deal to do with the size and the cost of the machine. The higher the speed the smaller the dynamo. But there is a practical limit to the number of revolutions per minute. It is determined, first, by the nature of the motor to be used in driving, and secondly, by the requirements of the armature shaft and commutator. Speeding above 1,500 revolutions per minute is uncommon; so is speeding below 500 revolutions per minute. A very usual rate is 1,000 for a land dynamo and 800 or even less for a machine to be used aboard ship. Let us suppose that a dynamo is required to be run at 1,000 revolutions.

(2) The electromotive force required must be known —that is, the E.M.F. required for useful purposes. This will depend upon the work to be done. For arc lighting it may have to be very high, and for

incandescent lighting very low. For the latter it will depend upon the voltage of the lamps. These may be roughly regarded as taking an E.M.F. of either 50 or 100 volts. Dynamos yielding the latter E.M.F. are very commonly used for electric lighting. Over and above this pressure, allowance must be made for two causes of loss, or drop of pressure. These are (*a*), the internal resistance of the machine itself, and (*b*) the resistance external to the machine, in the form of leading wires. The former will depend upon the kind of machine, but an allowance of 10 per cent. is frequently made for it. The latter can to a certain extent be arranged to suit the dynamo, but an allowance of 10 per cent. is commonly made in respect of it. Working upon these lines the dynamo would have to develop 120 volts, 110 of which would be available at the terminals for external purposes. For use aboard ship 50 to 80 volt slow speed dynamos are very commonly used.

Current, as we have seen, will depend, according to Ohm's law, upon (1) the electromotive force, and (2) the resistance of the whole circuit. The number of ampères can therefore be got in the ordinary way. The resistance must be such that at least half an ampère is available for each 100 volt lamp, and about one ampère for each 50 volt lamp.

The total electromotive force of the machine depends upon (1) the number of magnetic lines that flow from pole to pole of the field magnet, through the armature, (2) the number of turns of the armature wires in series at one time, and (3) the peripheral speed of the armature.

If we represent the total E.M.F., or that actually generated by the armature, by the letters $E_a$, And the proportion of it available for external useful purposes at the terminals of the machine by $E_e$,

The internal resistance of the dynamo armature and field magnets by $R_i$,

The external resistance, or that due to leading wires and lamps by $R_e$,

The current in the armature by $C_a$,

And the external current (or proportion of the internal) passing through the lamp circuits by $C_e$,

$$C_a = \frac{E_a}{R_i + R_e} = \text{Total current},$$

And $$C_e = \frac{E_e}{R_e} \text{ the external current.}$$

In the scheme of a new dynamo the magnetic circuit is the most important consideration. This should be composed of the softest iron, and it should be as short as possible. Its permeability to magnetism, as we have already seen (p. 54), should be as great as possible—this implies the greatest thickness of iron. If cast iron be used a much larger section, in accordance with its permeability, must be employed. The magnetic circuit may be taken as a line passing through the length of the field magnet and across the armature.

Professor Jamieson[*] proposed the following method of dealing with the magnetic circuit, and its relations. The mean length of the magnetic circuit is indicated by the letters $L_m$. The air spaces (between armature periphery and magnet poles), are marked $L_{as}$. The path of the divided magnetic circuit through the armature is called $L_a$.

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[*] Paper read before the Institution of Engineers in Scotland.

The magnetic circuit $L_m$ has a magnetic reluctance.*

$$R_m = 2\frac{L_m}{S_m},$$

where $2 =$ Kapp's coefficient for the initial specific magnetic reluctance of soft wrought iron. The number 3 to be used if the core be of cast iron.

$L_m =$ the mean length of field magnet circuit in inches.

$S_m =$ sectional area in square inches (at right angles to $L_m$ of magnet core).

*Reluctance of the Air Spaces.*—These $L_{as}$, $L_s$, have a reluctance

$$R_{as} = 1440\,\frac{2\,L_{as}}{S_{as}};$$

where the number $1440 =$ Kapp's coefficient for the specific reluctance of air and copper; when wrought-iron magnets are used (1800 to be used with cast-iron magnet cores and pole pieces, and 1500 with wrought-iron cores and cast-iron pole pieces).

$L_{as} =$ depth of each air space in inches (and since there are two spaces, $2\ L_{as}$ is inserted in the formula).

$S_{as} =$ sectional area of air space or surface area of each pole piece in square inches.

*Reluctance of Armature Core.*—The armature core circuits, $L_a$, $L_a$, have a magnetic resistance—

$$R_a = \frac{2\,L_a}{S_a};$$

where $L_a$ = mean average length of armature core magnetic circuit in inches (if there was but one path instead of two we should have to multiply by the coefficient 2, but $2\frac{L_a}{2} = L_a$).

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* "Resistance" in the original paper.

$S_a$ = cross sectional area of armature core in square inches, = twice the radial depth × length of armature core.

*Total Magnetic Reluctance.*—The total magnetic reluctance of the complete magnetic circuit is therefore—

$$R_m + R_{as} + R_a = 2\frac{L_m}{S_m} + 1440\frac{2\,L_{as}}{S_{as}} + \frac{L_a}{S_a}.$$

*The Magnetic Lines.**—The total number of Kapp lines, $K_L$, of magnetic force which pass through the magnet and air space can therefore be calculated by *dividing* the ampère-turns ($A \times T_{mw}$) on the magnet windings by the total magnetic reluctance in the magnetic circuit,

or,
$$K_L = \frac{A \times T_{mw}}{R_m + R_{as} + R_a},$$

*i.e.*,
$$K_L = \frac{A \times T_{mw}}{\frac{2L_m}{S_m} + 1440\frac{2\,L_{as}}{S_{as}} \times \frac{L_a}{S_a}}.$$

*Electromotive Force in Armature.*—The E.M.F. developed internally in the armature winding is—

$$E_a = K_{La} \times T_{aw} \times N_{ar} \times 10^{-6},$$

where

$E_a$ = E.M.F., developed in armature in volts,

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* *Kapp lines.*—To give the magnetic line a convenient magnitude, Mr. Gisbert Kapp proposes a line = 6,000 c *g s* magnetic lines. The number 6,000 is made up of two terms, viz., 60, which enables revolutions to be counted per minute instead of second; and 100 to bring down the measurement of the magnetic lines to reasonable numbers, or

$$\frac{c\,g\,s \text{ lines}}{60 \times 100} = \frac{c\,g\,s \text{ lines}}{6{,}000}.$$

Then, 1 Kapp line = 6,000 c *g s* lines.

Since there are 6·4514 square centimetres in a square inch,

$$1 \text{ Kapp line per sq. in.} = \frac{6{,}000}{6{\cdot}4514} = 930 \text{ c } g\,s \text{ lines per sq. centimetre.}$$

$K_a$ = Kapp lines which only pass through armature or the useful field,

$T_w$ = turns of armature wires in series, counted all round core.

$N_a$ = number of armature revolutions *per minute.*

*Example I.*—Let us now apply the foregoing formulæ to the design of a single field compound dynamo.

Let the dynamo be furnished with a long shunt, and be of 6,400 watts (external power $P_w$), when driven at 1,000 revolutions per minute.

First, let us determine the resistance, current, fall of potential in armature and magnets, and percentage loss of power in the armature, shunt, and main field magnet coils, using the same symbols as before.

Given $$E_e = 100 \text{ volts}$$
$$C_e = 64 \text{ ampères.}$$

*Resistance.*—Then $R_e = \frac{E_e}{C} = \frac{100 \text{ v.}}{64\,a} = 1{\cdot}55$ ohm.

Suppose we agree to a loss of about 10 per cent. of the total power in the dynamo, or say—

The electrical efficiency of the dynamo = 90 p. c.

$\therefore$ 90 per cent. : 100 per cent. :: 6,400 $P_w$ : $x$,

$\therefore$ total power = $x$ = 7,100 $P_w$.

Let $$R_a = \frac{R_e}{20} = \frac{1{\cdot}55}{20} = {\cdot}077\ w.$$

Let $$R_s = R_a \times 1{,}000 = {\cdot}077 \times 1{,}000 = 77\ w.$$

Let $$R_m = 75 \therefore R_a = \tfrac{3}{4} \times {\cdot}077 = {\cdot}058\ w.$$

Now the external current = current in armature field and magnet main coils less the current in shunt.

*Currents*, or $C_e = C_a - C_s$.

But $$C_s = \frac{E_e}{w} = \frac{100 \text{ v.}}{77\ w} = 1{\cdot}3\ a;$$

$$- 1{\cdot}3\ a,$$

$$C_a = 64 + 1\cdot3,$$
$$= 65\cdot3 \text{ ampères.}$$

*Fall of Potential in Armature.*

$$= C_a \cdot R_a = 65\cdot3 \times 0\cdot77,$$
$$= 5\cdot02 \text{ volts.}$$

Fall of Potential in Magnet Main Coils,

$$= C_m \cdot R_m = 65\cdot3 \times 0\cdot58$$
$$= 3\cdot78 \text{ volts.}$$

Total fall of potential in armature and magnet series coils.

$$= C_a \text{ or } C_m \, (R_a \times R_m),$$
$$= 65\cdot3 \, (\cdot077 + \cdot058) = 8\cdot8 \, v;$$
$$\therefore E_a = 8\cdot8 + E_e = 108\cdot8 \textit{ volts.}$$

*Percentage loss of power.*

In armature $= C_a{}^2 \cdot R_a = 65\cdot3^2 \times \cdot077$

$= 330 \, P_w :: 100 : X_a$

$X_a = 4\cdot63$ per cent.

In shunt coils $= C_s{}^2 \cdot R_s = 1\cdot3 \, a^2 \times 77 \, w$

$= 132 \, P_w;$

$\therefore 7100 \, P_w : 132 \, P_w :: 100 : X_s$

$X_s = 1\cdot86$ per cent.

In main coils $= C_m{}^2 R_m = 65\cdot3^2 \times \cdot058$

$= 248 \, P_w;$

$\therefore 7100 : 248 :: 100 : X_m,$

$X_m = 3\cdot5$ per cent.

Totalling the different percentage losses we have :—

In armature . $X_a = 4\cdot63$ per cent.
In shunt coils. $X_s = 1\cdot86$ „
In main coils . $X_m = 3\cdot5$ „

$9\cdot99$ p. c. or, say, 10 p. c.

*Kapp Lines in Armature Core.*—Before substituting the above data in Kapp's formula we must agree upon the turns of wire upon the armature at the understood 1,000 revolutions per minute. Let there be 36 commutator bars of 36 sections of wire in armature, which has been found sufficient to give a current of practically uniform E.M.F. The number of turns of wire in each section of the armature depends upon whether we use double or single winding, and upon the current and the resistance of the armature wire. As we shall see further on, from our trial drawing and calculations, we can get in six turns of wire to each section.

$$\therefore T_{ar}\ 36 \times 6 = 216 \text{ turns of armature wire.}$$

Let $N_{ar} = 1{,}000$ revolutions per minute;

now $E_a = K_L \times T_{ar} \times N_{ar} \times 10^6$

$$\therefore K_{La} = \frac{E_a}{T_{ar} \times N_{ar} \times 10^6}$$

$$= \frac{108{\cdot}8\ v.}{216 \times 1{,}000 \times 106} = 503{\cdot}7\,;$$

say $= 50$ Kapp lines in *Armature Core.*

To obtain a certain number of Kapp lines or magnetic induction in an armature core, it is necessary to give a greater magnetic intensity to the field magnet core, owing to the unavoidable leakage of magnetic lines which do not pass through the armature core.

*Dimensions of Field Magnet Core.*—In ordinary practice it is usual to assume that only about 80 per cent. of the field magnet lines pass through the armature core.

Therefore the Kapp lines in *field magnets* are—

$$80 \text{ per cent.} : 100 \text{ per cent.} :: 500 : x = 625.$$

We must now ascertain the dimensions of the field magnet core to carry the 625 Kapp lines. Suppose we consider the case of field magnet to be cast iron throughout (poles and core).

A safe working density is 9 Kapp lines per square inch.

$$\therefore S_m = \frac{625}{9} = 69{\cdot}4 \text{ square inches.}$$

$$= 9{\cdot}4 \text{ inches diameter (if round).}$$

In practice it is found that a dynamo magnet bobbin should be in length about 1¼ times its diameter to give the necessary space for winding or ampère turns.

$$\therefore 9{\cdot}4 \times 1{\cdot}25 = 11{\cdot}75 \text{ inches long.}$$

*Dimensions of Armature Core.*—It has been found advisable in designing the dimensions of the armature core of a dynamo having a field magnet of the form we are now considering, to make the diameter of its core slightly larger, and its length slightly less than the diameter of the field magnet core.

Therefore, calling the diameter of the Gramme armature core 10 inches, its length 9 inches, and allowing a density of 20 Kapp lines per square inch of core section, since it is made of the best permeable wrought iron,

We have $\frac{500}{20} = 25$ square inches total cross section of armature.

$$\therefore S_a = 25 \text{ square inches.}$$

Allowing 20 per cent. of total space for insulation between *laminated plates* in armature core we have

80 per cent. : 100 per cent. :: $25 : x = 31{\cdot}5$ square inches.

$$\therefore \frac{31}{2} = 15{\cdot}75 \text{ square inches in each half.}$$

$$\therefore \frac{15{\cdot}75}{9''} = 1{\cdot}75 \text{ inch radial depth of core.}$$

*Magnetic Reluctance of Field Magnet.* — Now, drawing armature and field magnets to scale, and allowing 2½ inches for depth of winding on field magnet bobbin and clearance for armature, we find the mean length of field magnet core $L_m = 44$ inches, and remembering that in a formula for the magnetic reluctance of this part of the circuit we have to use a co-efficient of 3 instead of 2, seeing that the core is of cast iron,

We have—

$$R_m = 3 \frac{L_m}{S_m}$$

$$= 3 \frac{44}{69{\cdot}4} = 19.$$

*Magnetic Reluctance of Air Space.*—With two layers of insulated conductors having a cross section of ·08 inch deep, by ·2 inch broad, including the covering, we find the total depth of air space on one side between pole pieces and armature core (allowing ·14 inch mechanical clearance equal to ·3 of an inch. Consequently, $2 L_{as} = 2 \times {\cdot}3 = {\cdot}6$ inch.

The bore of pole piece will be equal to the diameter of the armature core $+ 2 L_{as}$

$= 10$ inches $+ {\cdot}6$ inch $= 10{\cdot}6$ inches.

It is good practice to allow the corners of pole pieces to form an angle of 30° with centre of armature. The angle embraced by each pole piece will therefore be $180° - 30° = 150°$, which gives us a circumferential length of say 14 inches for each pole. And since our armature core is 9 inches long, and it is unusual to make the pole pieces broader than this length, we have

$S_{as} = 14$ inches × 9 inches $= 126$ square inches.

Hence—

$$R_{as} = 1800 \frac{2 L_{as}}{S_{as}}$$

$$= 1800 \frac{2 \times \cdot 3}{126} = 8 \cdot 5.$$

*Magnetic Reluctance of Armature.*—Referring to scale or full sized sections, we find by measurement that $L_a = 15$ inches. We have already determined $S_a$ to be 25 square inches.

Consequently $$R_a = \frac{L_a}{S_a}$$

$$= \frac{15}{25} = \cdot 6.$$

$$\therefore R_m + R_{as} + R_a = 1 \cdot 9 + 8 \cdot 5 + \cdot 6$$

$= 11$ Kapp units of magnetic reluctance.

*Ampère Turns.*—From formula for cast iron,

$$K_L = \frac{A \times T_{mw}}{R_m + R_{as} + R_a} = 625 \text{ (gross Kapp lines).}$$

$$\therefore A \times T_{mw} = K_L \, (R_m + R_{as} + R_a)$$

$= 625 \times 11$,

$= 6{,}875$ total ampère turns in shunt and main field magnet coils.

*Proportioning of Ampère Turns between Shunt and Main Coils.*—The total ampère turns have now to be divided in proper proportion between the series coils and the shunt coils of the field magnet windings.

In order to do this so as to give the desired form of characteristic curve, we must have recourse to actual experiment. The following method is carried out by many dynamo builders :—

1. A workshop bobbin or experimental coil, with a known number of turns of wire is kept for every size of dynamo machine made. This bobbin is put on to the magnet core in circuit with an ampèremeter, and is separately excited by another dynamo or by storage cells. The dynamo to be wound is run at the

normal speed with the external circuit $R_e$, equal to that of shunt, viz., 77 w., and with the voltmeter placed between the terminals. The exciting current through the experimental bobbin is now gradually increased until the required number of volts is observed on the voltmeter; *e.g.*, suppose the experimental bobbin to have 500 turns, and the ampèremeter reads 8·25 ampères when the normal voltage of 100 volts is reached, then the ampère turns of shunt wire

$$A \times T_{sw} = 500 \times 8{\cdot}25 = 4{,}125 \text{ ampère turns.}$$

2. Connect up the armature of the dynamo being constructed to a resistance equal to the joint resistance of the shunt and the normal lamp circuit through an ampèremeter, and run the dynamo at the normal speed. Now increase the exciting current in the experimental bobbin until the normal voltage of 100 volts and normal armature current of 65·3 ampères are both obtained. At the same time observe the exciting current.

But the total required ampère turns = 6,875, and from experiment we found that 4,125 ampère turns produced the requisite E.M.F.

$\therefore 6{,}875 - 4{,}125 = 2{,}750$ ampère turns left for series coils.

3. The normal current at full load required to pass through the series coils was found to be 65·3 ampères.

Consequently the number of turns required in the series coils

$$= \frac{2{,}750}{65{\cdot}3} = 42 \text{ about.}$$

4. From experiment 1 we found that 4,125 ampère turns give us the required excitation to produce the

normal E.M.F., and from our former calculation we found that the current in shunt

$$\therefore \frac{4{,}125}{1{\cdot}3} = 3{,}173 \text{ turns.}$$

$$C_s = 1{\cdot}3 \text{ ampère.}$$

But the series coils are also carrying the 1·3 ampère required for the shunt when dynamo free.

$\therefore 3{,}173 - (42 \text{ turns} \times 1{\cdot}3\,a) = 3{,}173 - 54 = 3{,}119$ turns on shunt coils.

5. All we now have to do is to so proportion the size of our series and shunt coil conductors that they shall carry the necessary currents required in each case at the rate of not exceeding 1,000 ampères per sectional area square inch. For armatures this may be, and is in practice increased to even 3,000 ampères per square inch without undue overheating, owing to the cooling effect of the air carrying off the heat generated in the revolving armature. Mere radiation only acts on the field-magnet coils: therefore the sectional area is of necessity much greater.

# CHAPTER XIII.

## *DYNAMO GOVERNING.*

One of the earliest discoveries in the evolution of the dynamo was that the position of the brushes upon the collector or commutator might be made to determine the output of electricity therefrom. When the brushes were set exactly upon the neutral line, the current was found to be at its strongest. When they were moved to one side or the other the current fell off in strength. But although this plan was often resorted to in the early machines, it was not always satisfactory. Such a method may probably be left to control the current, but it is not sufficient to maintain a fairly constant electromotive force.

*Regulation by Shifting Brushes.*—Hence, regulation by means of shifting brushes was soon found better adapted to the case of running arc lamps in series than to that of glow lamps in parallel. In the former case a fairly constant *current* is very desirable, and the E.M.F. may be allowed to vary somewhat. In the latter case an unvarying potential is of the greatest importance, and this cannot be secured by merely shifting the brushes.

Many attempts have been made to utilise the brush-shifting method for lighting purposes. A great difficulty had, however, to be overcome. The real effect of shifting the brushes is to upset the electrical balance of the armature. Since its two halves are connected in multiple (in most armatures), each half yields an equal share in the potential and current. This occurs when the brushes occupy the neutral, or "line of best collection." When, however, they are moved away, the current in certain of the coils upon one side begin to oppose the current in equal coils upon the other side, the result being neutralization of the output of those coils. But those coils are still active. The result of moving the brushes is to rupture their circuit before the proper time, and a great increase in the sparking is the result. Normally, with the brushes upon the neutral line, one at least of these coils on each side will be short circuited by the brush; to shift the latter is to give these "dead" coils life, which is discharged in a shower of sparks.

This destructive sparking soon deterred inventors from introducing the method of shifting brushes, even for arc lighting. But the designers of the Thomson-Houston machine saw a way out of the difficulty, which was at least applicable to their dynamo. The chief objection to the sparking was its destructive effect upon both brushes and collector segments. This could, however, be obviated by blowing out the sparks by means of an air-blast, and to this automatic device alone is due the success of the Thomson-Houston dynamo in its feature of self-regulation. It is probably the only form of machine in which brush shifting has proved a success. In this dynamo the automatic moving of the brushes is performed by means of a regulating magnet in effect somewhat similar to the arrangement employed by Maxim in America, and by Statter and others in this country.*

*Governing by Speed.*—The output of a dynamo may be controlled to some extent by changing or varying the speed. This fact has led several inventors to devise gear the function of which is to control the speed by governing the steam engine. This method has not, however, come into general use, and it has many defects.

*Governing by Variable Resistance.*—Scarcely less satisfactory is the old method of maintaining a certain resistance in the circuit, and varying this to meet the exigencies of the work. This method involves waste of energy in proportion to the otherwise useless resistance included in the circuit, and is generally so crude that it is seldom resorted to.

*Variation of the Magnetic Field.*—It may be said generally that the most successful method of regulating the output of a dynamo consists in *varying the density of the lines of magnetism in the field.* This has a direct result upon the electromotive force evolved by the armature. It may be done in several ways. The most obvious method is, of course, to vary the "strength" of the field magnet by controlling its *excitation.* This opens up a wide field of inquiry, as it is possible to effect the required object by different methods, as *separate excitation*, *shunt winding*, *compound winding*, and the later *composite windings*. All of these we shall briefly describe, although some of them have already been spoken of (p. 44). Before, however, entering upon a consideration of the methods based upon varying the *exciting current*, it will be of interest to mention at least one ingenious means of varying the density of the lines of magnetism without in any way altering the exciting current. We refer to the method proposed and carried out by Mr. O. Firth.

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* A detailed description of the Thomson-Houston regulator was given by Mr. Kapp in the *Engineer* for August 28, 1885.

*Regulation by varying the Width of the Air Gap.*—Firth's method consists, briefly, in so arranging the two halves of the field magnet upon suitable slides that they may be separated or brought together, so varying the distance between the pole faces and the armature. The separation is effected by means of a screw gear, composed of a single shaft, upon the two halves of which are cut right and left-handed threads. These work in nuts attached to the magnet cores. The arrangement is extremely simple. From experiments made with a dynamo of this kind, it is shown that when the field magnet is closed up, and the machine is yielding its full output, as shown upon the voltmeter, a considerable separation of the two halves can be made before an appreciable effect is shown upon the E.M.F.

*Hand Regulation.*—Governing by hand consists in varying a resistance placed in the field magnet circuit by that means. It usually refers to separately excited dynamos. Since the exciting current is never very great, the loss involved in controlling it by wasting the surplus in the resistance coils in the form of heat is more than counterbalanced by the advantages gained. This may be effected automatically, although it does not appear that automatic regulation carried out in this way has met with general approval. Governing by hand may be applied to shunt-wound machines. This is Edison's device. The magnets being shunt-wound have a certain power of self-regulation. But in order to meet extreme demands for E.M.F., a set of resistance coils are kept in the shunt circuit. These are switched out as the potential of the dynamo begins to fall (by reason of the switching in of lamps). This method, like every other depending upon resistance, is to a certain extent wasteful. Edison has also operated this device by means of an automatic governor.

*In cases of Separate Excitation* the usual practice is to vary the resistance of the exciting machine's magnet windings. Separate excitation is becoming very common in the running of large dynamos. A small continuous current dynamo is reserved for the purpose. The method of governing the output of the main dynamo by controlling the exciting current of the exciter, is considered one of the best. Resistance coils are employed for this purpose. Since the current exciting the small dynamo is but a fraction of the whole to be controlled, the loss in resistance is sufficiently small to be of little moment. This control is generally exercised by hand. But it is a very common practice to arrange matters so that one continuous current dynamo shall furnish the current required for exciting the field magnets of several dynamos. It will be obvious, therefore, that the above method will not always be applicable to such a case as this. For any variation in the current given by the exciter will react impartially upon all the dynamos fed by it. This may be desirable or not, according to the nature of the case. It may answer if all the dynamos are feeding into a common circuit, and call for an augmentation or decrease of magnetism simultaneously. But if they are feeding into independent circuits such a method cannot be other than confusing. In the latter case, therefore, the control must obviously apply to each working dynamo separately. Hence, variable resistances are placed in their field-magnet circuits for this purpose.

*Resistance Regulators.*—These variable resistances consist in most cases of coils of iron wire, arranged as before explained and illustrated (p. 43, Fig. 18). The wire is sufficiently thick to prevent over-heating. (Nos. 8 to 16 of the standard wire gauge are generally used.) It is coiled upon some incombustible substance, with the turns well separated. One of the most usual methods is to coil the wire upon iron gas tubing, a layer of abestos millboard being interposed between them to prevent short circuiting. The coils may vary from a fourth of an ohm up to several ohms, rising by fourths. A series of studs with a contact lever working from a centre are then arranged so that any resistance from zero to the full effect may be switched into the circuit. The coils will heat. Care is therefore to be taken that (1) they are arranged upon an incombustible base, preferably slate; and (2) that they are so wound and separated that the heat may pass off into the surrounding air. Soldered joints are to be avoided in such apparatus. It should be so constructed that danger from fire is impossible, even if the coils should by accident be fused. Such arrangements are known as rheostats, or resistance frames, according to the forms they assume. In many cases ribbon iron is used instead of round wire. This form of conductor presents more surface to the cooling effects of the air than round wire. The ribbon is generally arranged in a zig-zag or corrugated form, so that a considerable length of it may be included between the sides of the "frame," the conductors being arranged in a number of parallel lengths across a square or oblong framework. In such forms of rheostat, contact plugs are generally used to throw in and out of the circuit the lengths of ribbon. This form of rheostat is now not so generally used as formerly. In some special cases German silver is employed instead of iron to form the conductors.

*Series Dynamos* may be said to be regulated by one of two methods. The first of these, that of shifting the brushes, has been already spoken of. The second is the more generally practicable. It consists in establishing a shunt wire across the magnets. That is, a variable resistance is connected across from the terminal where the main current flows into, to the terminal from which the main current leaves the magnet's circuit. This constitutes a short circuit, but it must present sufficient resistance to obviate the cutting off of too large a proportion of the current. When the dynamo is required to work at its full capacity, the resistance of the shunt would be equal to infinity, or no current would pass through it. When the dynamo is required to work at a small proportion of its capacity, the resistance of the shunt would be very much less, and a considerable proportion of the main current would flow through it. This method of governing a series dynamo is preferable to the old plan of varying the resistance ot the main circuit, but it is distinctly inferior to the device of winding the magnets themselves with wire so fine that it may in itself constitute a shunt. This is, in fact,*

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* Series winding has already been spoken of at p. 45, and again at p. 197.

*Shunt Winding*, and it is intended to act as a self-regulator of the potential. The effects of shunt winding have already been briefly considered (p. 46). The magnets of the machine are wound with coils of wire so fine that the resistance of this circuit is frequently 1,000 times that of the armature. The result is that very little current flows in the shunt when the work portion of the circuit presents comparatively little resistance. Hence, if the dynamo is feeding one arc lamp, the resistance of this compared to that of the shunt being small, leads away the greater portion of the current generated, and very little flows around the magnets. If another lamp be switched into the work circuit, the resistance of that portion will be increased; less current will flow in it, but more current will flow across the shunt, and so strengthen the magnet. The dynamo will thus begin to evolve a stronger current. If another lamp be switched in, a still greater proportion of the current will flow in the shunt, and the dynamo will evolve a still greater current. In this way a shunt dynamo may be said to regulate perfectly with regard to current (although, for other reasons, a constant-current dynamo has not yet been invented). Similarly, if the dynamo be feeding glow lamps connected in multiple across the mains, its electromotive force will be fairly maintained, even within wide limits of load. But it is impossible in such a machine to prevent the electromotive force from falling slightly. As more and more lamps are switched across the mains, the resistance external continues to fall, and the current to increase. Now, increased current in the mains implies diminished current in the magnet's circuit, and the result is, of course, a slight drop in the electromotive force evolved. This is shown by the "characteristic" of such a dynamo having a falling tendency. But this slight falling off in the power of the machine may be very easily regulated by inserting a *variable resistance in the shunt circuit.* This is operated, as before, by hand. When a small load is on the dynamo the whole of this resistance is in circuit. As the load increases, the lamps will begin to dim. It may here be mentioned that a drop of 5 per cent. in the potential will show greatly upon the lamps. The variable resistance is then diminished, allowing a greater proportion of the current to flow in the magnet's circuit, and so restoring the balance. A very little variation of the shunt resistance will suffice to regulate a shunt dynamo. This is especially the case if the armature's resistance is small. If the latter presented no resistance there would be, theoretically, no drop in the potential.

Although a shunt dynamo regulates so well under varying conditions of load, it is found to perform badly under variable conditions of driving. If the steam engine be unsteady, a shunt machine will be less satisfactory than a series machine in feeding arc lamps. This is due to the great self-induction of the shunt coils, wound as they are upon iron cores. It takes *time* to effect a change in such a circuit. While an increase or diminution of speed will instantly disturb the lamps, it will not so quickly affect the current in the shunt. Hence the lamp circuit is much more sensitive to the variations of the speed than the magnet's circuit. If the changes were slow, the shunt would presently recover its balance and meet the exigencies of the moment; but, as it performs but sluggishly, it fails to meet mom ations.

Shunt dynamos are, therefore, unsuited generally for feeding arc lamps, especially when the driving speed is apt to vary. On the other hand, a shunt machine performs excellently when the only changes involved are those of current and electromotive force. The arrangements of shunt winding have already been spoken of at p. 46.

*Regulation by Compounding.*—It has been said that the slight drooping tendency of the characteristic by a shunt machine may be obviated by employing a variable resistance in the shunt circuit. Many attempts have been made to render this part automatic, and with the greatest success. But a still better method of regulation has been obtained by combining the attributes of the series dynamo with those of the shunt.

The series dynamo has the merit that it is almost free from the evils, due to self-induction, mentioned above. The storing-up tendency of the long shunt coil is absent, or nearly so, in the short, thick series windings. The effect is that the self-induction of lamp circuit and magnets are more nearly equal. This allows of considerable variations in the driving or speed, without their being apparent in the lights. In other words, the magnet part of the circuit responds to a change of speed as quickly as the lamp part of the circuit, and both feel it equally.

When a dynamo is "compounded" by furnishing its magnets with a few turns of series winding in addition to the shunt coils, it immediately partakes of the character of the series dynamo in respect of non-sensitiveness to inequalities in driving. The real effect and function of the series turns is to compensate for the slight tendency to lose electromotive force when there is an increased demand for current in the lamp circuit.

If a shunt dynamo could be provided with an armature having no resistance, it would yield a constant electromotive force, whether the exterior resistance was small or great. This condition is, however, impossible, although dynamos have been constructed having conductors so thick in the armature that the resistance of this part is merely nominal. Nevertheless, these machines will lose some of their electromotive force when the external current becomes a maximum, because the volts in the working portion of the circuit are but a proportion of the whole, and not the whole.

This fault can, however, be overcome by sending the main current round the magnet so as to reinforce the field as soon as the current in the working part of the circuit becomes large enough to cause a drop in the electromotive force. It has been said that the falling off is due to the increased current. This increase of current, if it be sent round the magnet, however, reinforces the magnetization, and in this way *it is possible to make a compound wound dynamo increase in power faster than the load can be switched on*, provided we are dealing with glow-lamp lighting in parallel, and that the load is gradually increased. The "characteristic" of a compound machine would show a perfectly straight line; that is, the volts would be maintained the same while the ampères of current varied from light to full load. It is, indeed, comparatively easy to give the characteristic any desired shape. But most makers prefer to give the electromotive force a slight rise at full load. A well-designed compound machine will, therefore, show a slightly upward-sloping characteristic, as depicted in Chap. XV (p. 229). The arrangement of compound winding has been already spoken of at p. 49, and again at p. 65.

"*Composite*" *Field Dynamo.*—This method of governing a dynamo was first suggested by Deprez. It appears to have had a more extended application in America than elsewhere. It consists in taking an ordinary series wound machine, and adding thereto additional exciting coils fed by an independent source. It is, indeed, a combination of series and separate excitation.

One of the most interesting examples of the composite field method—applied as it has been to an alternating-current dynamo—occurs in the new "composite" field machine of the Thomson-Houston system. The armature of the dynamo is wound for alternating currents, and it revolves in a multipolar field for that purpose. These currents pass direct to the lamp circuit. But *below* the alternating-current windings (sometimes, however, side by side with them), and directly placed upon the core of the armature, occur a few turns of conductor forming an independent winding. The (necessarily alternating) currents from these turns are passed to a commutator upon the shaft. The function of this is to commute them to a continuous direction. They then pass into the exciting coils of the field, and constitute a self-excitation. The field magnets are, however, provided with two sets of coils. The second set is reserved for the current from a separate exciting machine. The self-exciting current may be regarded as a shunted portion of the main current. The machine may be regarded as a "compounded" alternating-current dynamo, of which we do not appear to have any examples in this country. In another form of the machine the self-exciting coils are wound upon all the armature cores except two. These are situated directly opposite to each other. They are excited by the current from the separate exciting dynamo. The main object in all such combinations is to secure an initial and independent field, which, being independent of the variations in the main current, affords every facility to render the dynamo self-regulating.

*Constant Current Regulation Impracticable.*—It will be observed that most of the methods of governing here described have for their object the maintenance of a constant potential, and are therefore adapted more especially for incandescent lighting. But many attempts have been made to regulate for constant *current*. So far these endeavours have not been attended with success. *Electromotive force* is the attribute of the dynamo, and can be predetermined. Current, on the other hand, depends entirely upon the total resistance in the circuit. The nearest method we have to constant current governing consists in the combination of a shunt machine with a separate source of excitation, acting in independent coils.

## CHAPTER XIV.

## *OUTPUT AND EFFICIENCY.*

THE electrical activity of a dynamo, or, as it is sometimes called, its electrical horse-power, can be readily determined, provided two matters are known. These are, first, the "terminal voltage," or the volts of electromotive force indicated by a voltmeter placed across the terminals; second, the "ampèrage," or the number of ampères, or volume of the current indicated by an ampèremeter put in the circuit. In the case of a series, compound, or separately excited dynamo, the voltmeter may be simply connected across from one terminal to the other, so preventing the armature from generating a current. In the case of a series dynamo it must either be temporarily separately excited, or the resistance of any leading wires used allowed for. This would be called running the dynamo upon open circuit. It is assumed that the fractional current set up through the voltmeter coil may be neglected.

The product of the volts into the ampères gives the rate of working, or the power of the machine. Power, or electrical activity, is usually expressed in terms of the unit of power—the watt. A watt is a volt-ampère. The product of volts into ampères, therefore, gives the electrical effect in watts; 746 watts = 1 electrical horse-power. If we compare the electrical activity (expressed in this way) with the mechanical power expended in moving the dynamo we have a determination of the "*efficiency*" of the dynamo. If a machine absorbs 100 horse-power from the engine, and returns an electrical activity of 90 electrical horse-power, its commercial efficiency is, of course, 90 per cent. The actual electrical efficiency of the machine will be greater than this, because it has to overcome the resistances of its armature and field magnet. A certain portion of its efficiency of conversion is, therefore, expended (and wasted as heat) in the machine itself. The *total* electrical effect includes this waste, and is generally known as the electrical efficiency. The useful, or external electrical effect is spoken of as the commercial efficiency.

The volt-ampère or watt is a convenient unit in terms of which to express the capacity of a dynamo. Machines may be specified as so many watt machines. A dynamo yielding 10 volts and 100 ampères may be called a thousand watt machine. Similarly, a dynamo giving 100 volts and 10 ampères would be a thousand watt machine. It would still remain a thousand watt machine if its E.M.F. were raised to 1,000 volts and its current diminished to 1 ampère.

The proposal, by the Board of Trade, to form a unit of electric lighting, having a magnitude of 1,000 watts or volt-ampères (also called, according to the decimal system, a kilowatt) has led many makers of dynamos to designate their machines as so many Board of Trade unit machines. Thus, a 10 unit dynamo would mean a machine capable of furnishing 10,000 watts. But dynamos are still in some instances designated by the makers' numbers or letters. It is still more misleading to speak of a dynamo as a so-many-lamp machine. A thousand lamp dynamo might possibly imply that the output was a thousand ampères at 50 volts, or it might imply something very different. Incandescent lamps take so many watts per candle-power. The consumption varies greatly, from about 3·5 to 5 watts per candle, and no two lamps, even by the same maker, can be absolutely equal in their consumption, save by accident. Arc lighting dynamos are very frequently spoken of as so many lamp machines. In this case the candle-power, effective, of the lamps should be known, but this varies with carbons, length of arc, and so on. Hence, the only practicable method of designating a machine's output is to give both its volts and ampères, or its watts.

In dealing with the output of dynamos through certain resistances, Ohm's law gives the necessary formulæ. C is generally used as the symbol of current (or ampères); E of electromotive force (or volts), and R of resistance (expressed in ohms). The law may be variously stated:

$$C = \frac{E}{R};\ R = \frac{E}{C};\ \text{and } E = R \times C$$

Or, in other words:

$$\text{Amperès} = \frac{\text{volts}}{\text{ohms}};\ \text{Ohms} = \frac{\text{volts}}{\text{ampères}};$$

$$\text{Volts} = \text{ohms} \times \text{ampères}.$$

The electrical activity or rate of doing work varies, in a circuit, as the square of the volts. If a volt be applied in a circuit whose resistance is an ohm, the current will be an ampère, and the work will be a volt-ampere or watt. If the electromotive force be doubled, or two volts, the current will also be doubled, so that the electrical activity will be four volt-ampères or watts. The electrical activity varies, as ampères × volts, and, therefore watts (or power) = ampères × volts.

The electrical activity or power also varies as the square of the current, for if the current in any given resistance is doubled, the electromotive force will also be doubled, and the power will thus be fourfold, or watts $= C^2 R$.

Electrical activity varies directly as resistance. If a resistance be doubled, with a current to be preserved constant, the electromotive force must be similarly doubled, or volts = ampères × ohms.

Electrical activity varies inversely as the resistance when the electromotive force is constant. If a circuit of a resistance of 10 ohms has in it an E.M.F. of 10 volts, there will be a current of 10 ampères, or 100 watts, of electrical work. But if the resistance be halved, or 5 ohms, the ampères will rise to 20, the volts remaining the same as before, so that the power will be increased to 200 watts.

*The Electromotive Force lost internally.*—As already stated, the electrical activity yielded by the machine for useful (or external) purposes is not the whole of the converted energy. A proportion is wasted in maintaining the current throughout the internal circuits of the machine itself. It is convenient to distinguish between the sources of loss. These are, usually, the armature (which always presents a certain resistance) and the field magnet coils, which generally offer considerable resistance. Experience dictates that certain proportions should be observed between these resistances.

Armature resistance should be kept down to at least $\frac{1}{50}$th of that of the external (or interpolar working) resistance. This applies to most cases of ordinary working, and gives the proportion between armature and lamp circuits.

In compound and series machines the resistance of the series coils should never exceed that of the armature. In the best machines it is considerably less.

In shunt-wound machines the resistance of the shunt should be at least 400 times as great as that of the armature. In well designed machines it is frequently as great as 1,000 times. This applies equally to the shunt coils of compound dynamos.

Hence, the current that can be set up round the shunt coils will seldom exceed 5 per cent. of that passing in the external or useful portion of the circuit.

Series machines are subject to the same law as the voltaic battery. The electrical effect is at a maximum when the current in the armature and in the external portion of the circuit are equal.

*Power absorbed internally.*—In a well designed compound dynamo the watts lost in the armature, shunt coil and series turns, seldom exceeds 10 per cent. of the total. It is distributed somewhat as follows:—armature, 4 per cent.; shunt, 4 per cent.; series coil, 2 per cent.

*Horse-power transmitted to Dynamo.* — This is measured usually by a transmission dynamometer, applied to the belt. The horse-power absorbed by the machine must be ascertained before attempting to determine its rate of conversion. This is generally effected by means of a dynamometer of the Hefner Alteneck type, as used by Dr. J. Hopkinson* in his tests of the efficiency of the Edison-Hopkinson machine, or by indicator diagram taken from the engine in the usual way.

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* See *Phil. Trans. of the Royal Society*, p. 347, 1886.

It may be useful to remark that although designers of dynamos endeavour to attain a high rate of conversion and commercial efficiency, a useful output as high as 90 per cent. of the energy absorbed in driving them is not a common occurrence. In Dr. Hopkinson's tests of the above-mentioned machine, 93 per cent. was shown, the remainder being lost as follows: power lost in armature, 3·17 per cent.; lost in magnet windings, 1·66 per cent.; lost in core, 1·94 per cent. These figures show that as far as efficiency is concerned, there is little further to be gained in the future development of dynamos.

## CHAPTER XV.

### *GRAPHICAL RECORDS.*

MECHANICAL engineers are in the habit of exhibiting the working of a steam engine by means of a curved line. This is well known as an indicator diagram. The application of the same principle to the dynamo machine is due to Deprez, and to Dr. Hopkinson, who first pointed out its advantages in a paper read before the Institution of Mechanical Engineers in April, 1879. This paper contained several results deduced from tests made in this way upon a Siemens series dynamo.

But while, in its application to the case of the steam-engine, the curve is usually obtained automatically by means of a pencil, moved under the control of a diagram indicator, in the case of a dynamo it has to be plotted out from certain values obtained under different conditions, as of speed and load. Since the publication of this paper the graphic method of recording experiments with dynamos has come into general favour. It is doubtless to be preferred, in most instances, to an algebraic method, over which it has many advantages. It shows, at a glance, the performance of a machine. It indicates unmistakably not only its excellences and faults, but can be made to exhibit the electrical horse-power it evolves, and its relation to the most economical speed. The diagram shows the relation subsisting between the magnetism, the armature, and the windings. There is scarcely a question of importance that cannot be elucidated by means of a curve. The graphical method has doubtless commended itself to practical men because of its intrinsic advantage of being very easily understood. It forms a line-picture of the working easily read by persons unversed in even the symbols of algebra.

In 1881 M. Deprez, who had developed the method, and applied it to many useful purposes, suggested the term *characteristic* curve, a proposal which has met with general adoption. Hence it is common to refer to a particular curve as the "characteristic" of the dynamo.

A graphic record is intended to show the result of a series of experiments. It may prove useful to describe the method followed in obtaining the curve. The paper upon which the line is to be drawn is to be divided into small squares, by means of straight lines drawn at right angles to each other. This paper is to be obtained commercially, already lined, with considerable accuracy, under the name of *squared paper*. In one of the most useful forms of the curve two sets of values are obtained by experiment upon the machine. These are plotted as dots, as represented in the diagram (Fig. 73, p. 222), according to their position in relation to two scales laid off at right angles to each other, vertically and horizontally. Hopkinson's curve was obtained from observations in which the abscissæ, measured horizontally, represent the number of ampères of current, and the ordinates, shown vertically, the corresponding values of the electromotive force.

In the drawing of these curves a sufficient number of points, or results, are first obtained. These are denoted at their exact corresponding positions in the squares, according to the scales, and a curved line is carefully drawn, so as to pass through, if possible, all the points. This is most easily done by means of the aid of an elastic steel ribbon, so bent as to pass through the points, and a line run through them with pencil or pen. The divisions of the paper may be taken to represent single ampères or volts; or, if the values are likely to be large and the scale limited in size, tens of each may be supposed to be included in each division. But it will be obvious that if the squares are only small size it will be a difficult matter to subdivide them into ten parts in endeavouring to find the exact point for any obtained value between one and ten, and so on. Hence, squared paper upon which curves are to be drawn should be large. Each division should be of a good size, and, if practicable a division should be taken to represent a single ampère or a volt, as the case may be.

We have before (p. 54) referred to the use of these curves by both Rowland and Hopkinson in recording their experiments on the magnetic permeability of iron, and it will be obvious from this that any two sets of results may be scaled upon the horizontal and vertical lines, as intensity of magnetism and magnetizing current, permeability and magnetic induction, and so on. Attempts have been made to apply an automatic indicator to the dynamo, but the instrument has not yet come into general use.

In Dr. Hopkinson's curve (Fig. 73) the speed was kept constant. The electromotive force depends upon the speed, the turns of the armature wire, and the intensity of the magnetic field. Since the speed and the turns of the armature wire did not vary, the steep part of the curve, showing a rapid rise in the electromotive force, can only be attributed to the increasing intensity of the field. This is shown to bear a very significant relationship to the total, or magnetizing, current. The curve fulfils its purpose in exhibiting graphically the relationship between the current and the electromotive force under those conditions. Keeping the speed constant, the current was varied simply by inserting resistances in the circuit—that is, inserting a high resistance, and gradually diminishing it—as in the following columns—figures

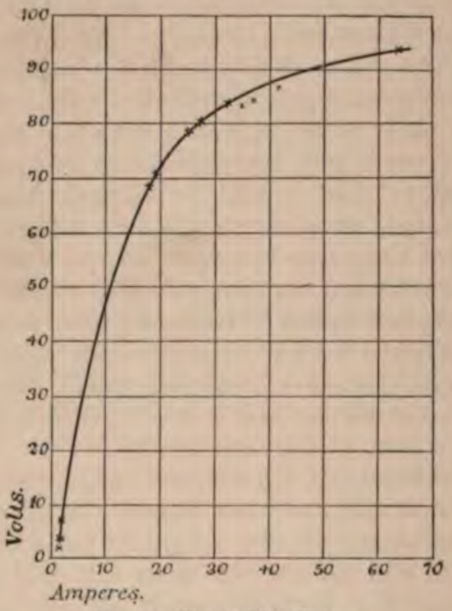

Fig. 73.—Characteristic Curve.

which correspond with the points plotted in the diagram. It must be remembered that the volts and ampères must be drawn to the *same scale* in forming the curve.

Values Relating to Graphical Record in Fig. 73.

| Resistance in Ohms. | E.M.F. in Volts. | Current in Amperes. |
|---|---|---|
| 8·3 | 3·95 | 0·48 |
| 5·33 | 7·73 | 1·45 |
| 4·07 | 68·4 | 16·8 |
| 3·88 | 70·6 | 18·2 |
| 3·205 | 79·5 | 24·8 |
| 3·025 | 81·1 | 26·8 |
| 2·62 | 84·4 | 32·2 |
| 2·43 | 83·8 | 34·5 |
| 2·28 | 84·6 | 37·1 |
| 2·08 | 87·4 | 42·0 |

*Horse-power Curves.*—But the curve is sufficient to afford still further information. If drawn to a scale it can be made to show the horse-power evolved. If we multiply the ampères by the volts the product represents the electrical activity in watts. In the electrical horse-power there are 746 watts. Hence it is practicable to calculate the horse-power relating to any given point of the curve, because that point indicates at once both values required.

But the values may exchange names, and the rule still holds good. If we, taking the first case, find that we can set off horse-power points at the intersection of the two values which, multiplied together as above explained, give the required 746 watts, it will be evident that there will also be a point where the smaller value may be exchanged for the greater, and that this will give us a *line* of horse-power. For example, horse-power lines will pass through all those points in the diagram where volts into ampères will give 746, or multiples of 746. Either 37·3 volts and 20 ampères, or 20 volts and 3·73 ampères, will correspond to one horse-power. It is usual to plot out these electrical horse-power lines, so that a separate curve can be given for each horse-power, as represented in Fig. 75. Thus the graphic record,

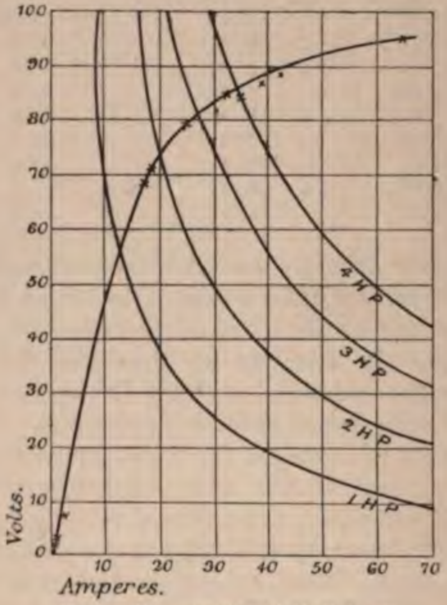

Fig. 74.—Characteristic with H.-P. Lines.

so far, affords a great deal of information relating to the dynamo of which it is a characteristic. But the work-picture thus drawn can be still further elabo- ted. The curves just spoken of are known as the se-power characteristic.

*urve of External Electrical Activity.*—The main curve first plotted out gives obviously the *total* electromotive force of the dynamo. The available E.M.F., or that at its terminals, is somewhat smaller than this. If the E.M.F. required to overcome the resistance of the armature and that of the field magnets be deducted from the total, another curve is obtained considerably within the main curve. This is marked *external* to distinguish it from the total electrical activity. Hence, in calculations from a diagram it is the external curve that is to be considered if these considerations are to apply only to the activity in the exterior or useful portion of the circuit. This curve is known as the external characteristic.

*Line representing Internal Resistance.*—By deducting the electromotive force required to overcome the resistance of armature and field magnet coils for different values, a line corresponding to the internal resistance can be drawn. The points cut by this line show at a glance the volts lost corresponding to different strengths of current. Dr. Hopkinson plotted out the internal line by multiplying the resistance of the armature by the current which represented the electromotive force required for overcoming it, and by deducting this from the total. Hence, loss due to internal resistance can be represented by either the curve of external activity or by the line of internal resistance.

*Variable Speed Curve.*—If the speed be varied, as was done by M. Deprez, a series of curves is obtained, exhibiting the relation of speed to electromotive force. Up to a certain point, critical for each dynamo, the E.M.F. is, generally speaking, proportional to speed. In the case, however, of a series dynamo the critical speed may be said to vary somewhat with the resistances in circuit.

## Graphic Record of Shunt Dynamo.

In a series machine, as the external resistance is diminished, the current is increased, and the E.M.F. rises rapidly, until the magnets are saturated. The E.M.F. then falls off for any further diminution of the external resistance, showing a drop in the continuation of the curve. Hence for considerable variations of external resistance the current is maintained fairly constant. Thus in the characteristic just given the current only rises to the extent of 20 ampères, while the E.M.F. increases from 0 to 70·6 volts, and while the resistance, as shown in the table (p. 223) varied from 8·3 ohms down to 3·88 ohms, the better the proportions of the series machine the less the variation in the current, the steeper the slope of the curve.

If we now consider the case of a shunt dynamo running on open circuit, its initial interpolar E.M.F., if intended for incandescent lighting, might be as high as 110 volts. As current is drawn from the external circuit by gradually diminishing the interpolar resistance, or in other words by switching in lamps, the ampères should rise in proportion; but the resulting diagram, if the figure be plotted, would not show a practically straight line. There would be a downward tendency, due to a falling off in the E.M.F.; and this, in turn, would be due to the increased current. In a shunt machine having an excessively small armature resistance, and a magnetic circuit of the softest iron, the line would be practically straight, since under these conditions there would be little or no drop in the E.M.F. at full load. The defect of ordinary shunt machines, when tried in incandescent lighting, is that the E.M.F. is not maintained constant. But the slight drop may be compensated for by a few turns of the main circuit around the magnets, constituting a compound of series and shunt winding.

If a shunt machine diagram be plotted out, commencing with the machine on *short* circuit, working through a short, thick wire, and gradually increasing the resistance, a rapidly ascending curve is obtained, in which volts and ampères equally participate. This slope may be regarded as corresponding to magnet saturation. As the external resistance is still further increased, the volts continue to increase, but there is no increase in the current. As the resistance is carried still further the current falls off, as is usually shown by the curve bending back to the scale of ordinates, since the lost volts or drop of potential at full load is due simply to the fact that the armature plays an appreciable part in the total resistance, it may be shown that this corresponds to the angle formed by the drooping line, or is proportional to the vertical ordinates so enclosed.

A compound dynamo, as we have already seen, can be made to give constant potential, so that a diagram plotted from it would show, first, a rise of the line to the critical speed (or condition of full excitation), and then a sharp curve to the right, continuing thence as a straight line along the scale of abscissæ up to the full number of ampères the armature would safely evolve. The proportion between the shunt and series windings can be set forth in a graphic record.

As we have already seen in Chap. IV., the series or main coils should have a resistance rather more than 300 times (400 times is better) that of the armature. The effect of the series windings must be such as will result in such a diagram as is shown in Fig. 75, in which ohms of resistance are the abscissæ and volts the ordinates. This shows the relation between the E.M.F. at the terminals and the interpolar resistance of a compound wound machine. The shunt curve begins at 0, and rises finally to 110 volts.

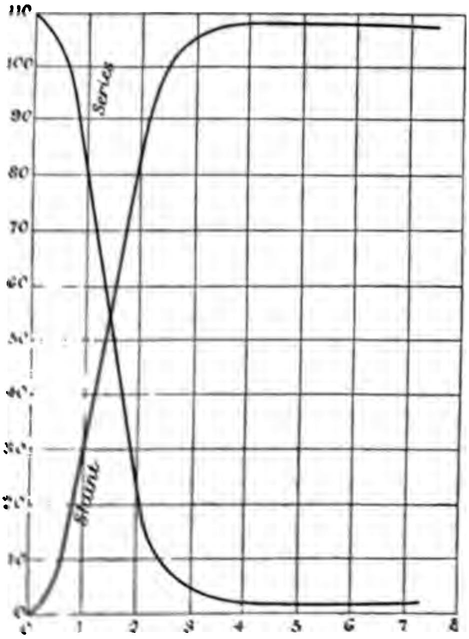

Fig. 75.—Characteristics from a "Compound" Dynamo.

The series curve begins at 110 volts and falls to 0. If the series and shunt coils are properly proportioned they will each give, at the same speed of armature, a curve crossing a certain point. In this case it is 55 volts. Their curves will cross at that value, and at 50 volts such a dynamo would give constant

E.M.F. If a diagram be plotted, as in Fig. 76, in which the current is taken as ordinates, and the volts as abscissæ, the horizontal part of the line should have no tendency to droop even at full current. If it falls its curve represents lost volts, and shows that the series coils are insufficient. If it rise slightly at full load that circumstance will, in practice, be found advantageous rather than otherwise. It is indeed the present practice to rather over-compensate, so as to give such a curve. But if the line should rise considerably, say, so as to show an increase of ten per cent. in the E.M.F., it shows that the series coils are over-sufficient. It should, however, be pointed out that any change effected in the series windings is apt to upset the relation previously subsisting between them at a certain critical speed, and that the true compounding may be still further departed from, unless that relationship, shown in Fig. 75, be re-established.

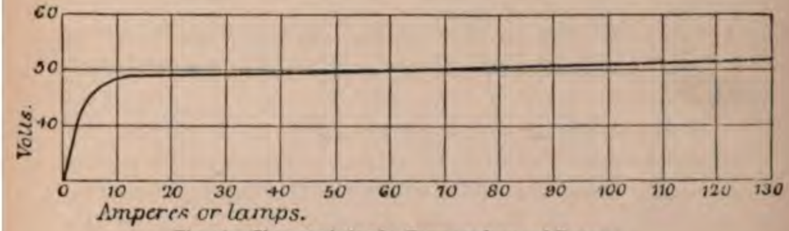

Fig. 76.—Characteristic of a Compound-wound Dynamo.

At pp. 286—290 are given two curves of magnetization, exhibiting the relationship between ampère turns and lines of force in the field of Kapp's dynamos.

## CHAPTER XVI.

### *DYNAMOS IN SERIES AND PARALLEL.*

To combine the outputs of two or more machines in a common circuit effectively, calls for some consideration.

It may be required to produce in a circuit an electromotive force of 100 volts. The machine power available may consist of two 50 volt dynamos, neither of which can do the work by itself. If, however, the machines can be run upon one circuit, similarly to two cells of a battery, their joint E.M.F. will be double that of one alone. This is *series working.*

On the other hand a current of 100 ampères may be required, at an E.M.F. as low as that of one machine only. Two machines are then to be coupled in multiple, which will have the effect of doubling the ampères while maintaining the volts equal to that of one machine. This is known as *parallel or multiple working.*

### Series Working.

Let us consider the case of series running first, and that with *series wound machines.* Given the case of two dynamos of equal power, it would only be necessary to connect the + terminal of the first machine with the − terminal of the second. The combined E.M.F. of both will then feed into the common circuit. This arrangement only works well when the dynamos are of *approximately* equal power. It must not be forgotten that this is a severe test of the insulation of both machines. If a dynamo be built and insulated to withstand its own E.M.F. of say, 50 volts, the 100 volts that would result from the combination with another machine might break down that insulation, leaving the covering of the wires pierced in numerous points, where the potential difference happened to be greatest. Strictly speaking, series running is thus only applicable, first, to well insulated dynamos, and secondly, to machines not differing greatly in their volts.

*Shunt-wound Dynamos in Series.*—Shunt machines will not work well in series unless the two shunts be first put in series with one another. The two shunts are then to be treated as one long shunt. The same precautions with respect to insulation have to be observed as in the case of series machines. For reasons already mentioned, the running of dynamos in series is very seldom resorted to. But in some cases of arc lighting, where the build and insulation of the armature and coils are particularly well adapted for high potentials (as in Brush's dynamos) arc lighting is successfully carried out on this plan. At best, however, it cannot be regarded by engineers as anything better than a makeshift, in which a temporary use of two dynamos has to be substituted for one machine of the requisite E.M.F.

## Parallel Working.

By the use of two dynamos in parallel circuit a gain of as much as 20 per cent. is frequently obtained.

That is, the combined current is stronger than the two currents, flowing in separate circuits, added together.

*Series-wound Dynamos in Parallel.*—A good deal of difficulty is experienced if it be attempted to connect machines simply in parallel; that is, both + poles to one lead, and both − poles to the other lead. Indeed, as thus simply arranged they cannot work to advantage unless they are of exactly equal voltage and continue to run at the same rate of speed. If one of the machines should have a lower E.M.F. than the other, the stronger machine will force part of its current through the weaker, thereby finding a partial short-circuit, and will ultimately reverse and drive it as a motor. For many years this difficulty stood in the way of parallel working with series machines, until M. Gramme pointed out that as it is impossible to maintain perfect uniformity of electromotive force in both machines, a path can be opened to take the excess from either, without interfering with the weaker dynamo. Gramme pointed out that if both the + poles be joined to one leading wire (and both the − poles to the other), the + brushes form practically neutral points between the two dynamos *except when there is an excess of E.M.F. on one side.* Hence, if the two + brushes be connected across with a wire, the excess may find a short circuit by that path, instead of flowing through the weaker dynamo. This cross connection of the brushes may be applied to either the positive or negative side. It will be evident that as the preponderating E.M.F. is short circuited, it will scarcely prove economical to run series dynamos not approximately equal in power and moving at the same speed in parallel.

Series dynamos may be run without any difficulty by the simple expedient of causing one to excite the other's field magnet, and *vice versâ*. This method has the additional advantage of acting as a constant current equaliser.

*Shunt-wound Dynamos in Parallel.*—On the other hand, the running of shunt machines is very easily effected. It was first introduced on a large scale by Edison, who showed the principle as applied to incandescent lighting, first in this country at the Holborn Viaduct lighting station. The nature of the circuits in this case is such that a reversal can only take place when the disproportion between the two machines is very great. For example, suppose one of the machines to cease giving current, the current from the other machine would flow through its armature and convert it into a motor. But this never takes place under ordinary conditions. The requirements of incandescent lighting are such that a pair of mains may, up to a certain hour, be supplied amply by one dynamo. The demand for current may then increase, necessitating the application of greater dynamo power upon the same circuit. The need for a fresh machine is indicated by the ampèremeter denoting that the single dynamo is working up to its full capacity. Any further demand would, then, overheat this dynamo. But it is impracticable to merely switch on a fresh dynamo without preparing it. If this were done the result would be disastrous to the lamps, and might bring the whole arrangement to a standstill. The fresh dynamo is invariably "built up" before switching in. That is, the machine is set in motion and its circuit closed in a group of lamps, or a rheostat. The resistance of this is varied until the machine's ampères and volts agree with those of the first machine. At this point it is switched on to the mains, and immediately takes half the load. The temporary bank of lamps or rheostat is switched out at the same time.

*Compound-wound Dynamos in Parallel.*—It is practicable to run two similar compound machines in parallel by merely adopting the above plan of causing each to excite the other's *series* exciting coils only. This is frequently done, but it is doubtful whether the device is applicable to the exigencies of an electric-lighting station. It has the disadvantage that, without loss, dynamos of different capacities cannot be worked together. If compound dynamos are simply connected in parallel, without resorting to the above device, they tend to overpower each other; in other words, if one of the machines happens to gain the ascendency, it not only maintains it but begins to force or dam back the current of the other.

Gramme's short circuiting method is, however, equally applicable to compound machines, and is now largely used in lighting stations, proving its perfect adaptation to the exacting requirements of such work. The device consists merely of a cross connection between the two + brushes of the machines. In lighting-station work, this connecting wire is provided with a switch. There is also a switch in each of the shunt windings, where they leave the – brush. Another switch upon each machine is interposed between the main lead and the – brush. These switches are required in "switching in" the fresh machine at the moment when the load upon the other has attained a maximum. Let us suppose such a case. The switches of the working dynamo will, of course, be closed. The operation observed in throwing in the fresh machine is very simple. The machine is set in motion at the normal speed. Its shunt wire switch is then to be closed, thus exciting its field magnet. The switch on the cross connecting, or Gramme wire, is next closed, and finally its — terminal with the main lead. If this is done in the order given, the lamps in circuit will evince no sign of any disturbance in the circuit. When it is required to cut out the auxiliary machine, the order of switching is to be the reverse of the above.

Either shunt or compound dynamos tend to pull each other into uniform working. If one of the machines happens to slow down, its output will diminish in proportion, and it will demand from the engine less power. There will immediately be a tendency in this dynamo to race, while the temporary failure in its output throws more work upon the remaining machine, which will, in turn, tend to move more slowly. Thus, there is between the two dynamos a continual self or mutual adjustment, each pulling the other into work as required. It is evident that this tendency can be taken advantage of to run dynamos of different capacities in parallel, and this, indeed, is frequently done in incandescent lighting. Difficulties, however, are more likely to arise in working very dissimilar dynamos together. Unless the "compensation turns" of the two machines bear a certain fixed ratio to their output, the machines may regulate very badly. The resistance of these turns should be inversely proportional to the respective capacities.

*Alternating-current Dynamos in Parallel.*—The usual alternating current consists of waves or impulses. A wave, starting from zero, is impelled through the circuit, it reaches a maximum and curves downward to zero. Let us call this a positive wave. It is followed by a similar wave, again starting from zero, attaining its maximum and falling to zero; but inasmuch as this second wave is determined in the opposite direction to that of the first, we call it a negative wave. The period of time taken to begin and complete the back and forth waves, determined the *phase* of the dynamo; the phase then, being practically the *periodicity* of the machine, is determined by the speed of the armature. This varies in different machines. But the number of armature and field-magnet poles also varies, so that one dynamo, having, say, twenty of each, would, at a given speed, have a periodicity twice as high as that of a machine with ten poles of each only. In order that these to-and-fro waves may be used to illuminate incandescent lamps, without there being apparent in the latter any sign of rise and fall of current strength, or reversal, the periodicity must be high.

The symbol ∿ is generally used to denote periodicity or phase. Thus, it is said that an alternator gives 100 ∿ per second, meaning that there are fifty positive and fifty negative waves in that period of time. This periodicity occurs in different machines at rates varying from about 80 up to 300 ∿ per second.

The principles underlying the practicable working of alternating dynamos in parallel, were first published by Mr. Wilde, deduced from experiments with his alternating machine.* The theory has subsequently been elaborated by Dr. John Hopkinson and others, and a very full investigation of the subject is given in Hopkinson's paper.*

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* *Phil. Mag.* i. 1869.

When alternators were first put in parallel across the mains of an incandescent lighting circuit, it was believed that only machines having exactly equal periodicity could be yoked together. Subsequent experience, however, has shown that a dynamo having a period or phase recurring at some multiple —generally a small multiple—of that of another dynamo may be worked together with it. Alternators of the same periodicity are in practice generally employed, because (it is to be presumed) there is less risk of confusion in switching in the fresh machine.

*Series Running impracticable.*—It is theoretically possible to work two alternators in series. But considerable difficulty will necessarily be found in maintaining the respective phases exactly the same. The difficulty of realising it in practice would be insuperable for the following reason: there are, say, fifty periods of positive maximum and an equal number of periods of negative maximum, occurring in a second of time. If we suppose the two dynamos to arrive at positive maximum at the same instant, they will work perfectly so long as this holds good. But if one of the machines were to quicken its period, from any cause, *to the extent of half of a phase*—or, in other words, become accelerated in speed *the hundredth part of a second*—that dynamo would then be arriving at its negative maximum, while its fellow would attain positive maximum. Now, since two opposite and equal electrical currents neutralise each other, there would be no current from either of the machines in the mains. We have supposed the extreme case of the dynamo becoming accelerated in speed, or its fellow lagging behind, to the full extent of half a wave, but in practice this would not be likely to occur all at once. But if from any cause one of the machines altered its phase in the minutest degree, the action of the other machine would be, not to pull it back into phase, but to throw it further and further out of phase, because more work would be required of the slow machine, which would tend to still further slow it. This is very clearly shown by Dr. Hopkinson, by graphic and other proofs.

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* *Proc. Inst. Civil Eng.* 1883.

On the other hand, parallel working shows a state of things exactly the reverse of this. Alternating dynamos, in fact, *tend to pull one another into phase or agreement.*

*Switching in Parallel.*—The conditions under which alternators are used, are generally as follow: For feeding a system of incandescent lamps, the mains may have a capacity for the output of several dynamos. During the early hours of the evening only a small proportion of the lamps upon the mains may be alight. As darkness sets in, lamps are turned on and the output of, say, the single alternator, may have to be increased from time to time (either automatically or by hand government), until its load is as great as the dynamo is known to be capable of maintaining without overheating. It now becomes necessary to switch on another alternator. This obviously would not be done until the speed of the fresh machine had attained a maximum. But if the fresh alternator happened to be at exactly the same phase, and by a rare chance the same pe as the first machine, it would take half the load without in the least disturbing the brightness of the lamps, and once yoked together the two would work in perfect unison.

Only, however, by chance would the fresh machine arrive at this exact condition or fall *into step*, and such a rare contingency is never relied upon. If switched in when not "in phase," the fresh machine would, it is true, be quickly pulled into unison, but meantime the lamps would be certain to suffer very severely. Several rapid extinctions and relightings might take place, and in addition to the obvious disadvantages of this in public lighting, the machines would probably suffer injury to their insulation. Accordingly a plan for bringing the new machine into perfect unison with the working machine is essential, and the method adopted is aptly termed the

*Synchronising of Two Alternators.*—Various devices and methods have been employed in order to ensure that the two machines are working in perfect unison. Alternators are almost invariably separately excited. The first step, then, is to bring the armature up to full speed. Then to switch on a small exciting current and to gradually increase this until the ampère and voltmeters in the machine's circuit show volts and ampères agreeing with those of the working dynamo. In addition to these precautions, and sometimes indeed independent of them, a single lamp is used, through which only the fresh machine is put in parallel with the working machine. When this lamp is fully lighted up, and thus perfectly steady, the main switch is shut, bringing the two machines upon the same mains. If this is carefully done, even with the aid of a lamp alone, no disturbance of the main lighting will ensue.

These precautions are taken when dynamos are driven by belts, either from one or two engines. But alternators are frequently driven by direct gearing with the engine shaft, and the fresh dynamo is merely clutched on. If the clutch is positive, allowing of no slips, very little appears to be left to be done beyond so regulating the field magnet current that the armature shall develop the required electromotive force. But in the case of a friction or flexible clutch, where slip may possibly occur, the machine should be treated as a dynamo driven by belting from an independent source.

## CHAPTER XVII.

## *THE DYNAMO IN ELECTRIC LIGHTING.*

WHEN an alternating current dynamo is used, the two carbons in the arc lamp waste equally. It is therefore a simple matter to make such a lamp focussing, or capable of keeping its arc at one point. When dynamo currents were first used for practical arc lighting in lighthouses it was the alternating current that was employed. When this current is employed for incandescent lighting there is said to be a similar equalization of the waste inevitable in the carbon filament. When a continuous current is employed there is a perceptible thinning away of the filament at one of the poles (the positive). The advantages to be derived in this way, however, from the use of an alternator dynamo are not sufficiently marked to warrant the exclusive use of alternating currents for glow lamps.

In the early days of the Alliance machine the magnetic field was obtained from permanent magnets. Later dynamos bear a certain similarity to the Alliance inasmuch as that they are almost invariably separately excited. There is this obvious advantage in the latter arrangement, that it affords an excellent means of controlling the electromotive force of the machine. Whereas the intensity of the field in a magneto machine was fixed, and depended upon th strength of the steel magnets, electro magnets ar easily controlled, and the E.M.F. of the dynam thereby raised or lowered by merely varying the exciting current. A device, having for its object th controlling of the magnetic intensity was formerl employed in the case of magneto machines. It consisted in placing a "divertor," composed of soft iro partially across the limbs of the magnet, so as t magnetically shunt off part of the lines of force, or i other words to magnetically short-circuit the magnet The electromotive force of the alternating curren dynamo can be altered by varying the speed of th armature, as well as by varying the exciting current and both methods are in use in large distributin stations.

*Compensation Excitation of Alternator.*—But alternators are frequently excited by a portion of thei own current. In this case a pair or more coils of th armature are put in circuit with the field coils, throug a commutator upon the shaft. This method allows o the exciting current being varied by the insertion o withdrawal of resistances generally by hand. A *compensated* alternator is similarly but partially excited the remainder of the exciting current being obtaine from a small transformer in the main circuit of th machine, the alternating impulses of which are connected to a continuous current by means of a commutator upon the shaft, as before. The object of thi recently introduced plan of partial excitation is t make the dynamo *self governing.* When properl arranged such a machine may be made to yield constant electromotive force. This is essential for th running of incandescent lam [illegible] all of potentia when fresh lamps are switched in is very small, hence a weak compensating current suffices to maintain the potential. Compensated machines of the alternator type being only of recent introduction have not been extensively used.

*Alternators and Transformers.*—Alternating-current machines are now almost invariably (when used in large distributing stations) employed to feed transformers. The function of the transformer is to convert currents of high E.M.F. into currents of low E.M.F., or the reverse. Small currents under high E.M.F. are more easily carried to great distances than large currents under low E.M.F. That is to say, a small or thin conductor may be used to convey current under high pressure, whereas the same amount of electrical power conveyed under low pressure would necessitate a large or thick conductor. Thus, an alternator develops an alternating current of 1,000 volts. This is conveyed in a thin conductor to the transformer, when it (or a portion of it) is converted or reduced to a pressure of 100 volts, which is used to feed the lamps direct. The principle of the transformer is almost identical with that of the ordinary induction coil. Ordinary transformers cannot be used with constant-direction current. Hence there is considerable advantage in the use of alternating currents for public electric lighting. So great indeed has been the success of the Ferranti, the Westinghouse, and the Mordey transformer systems that this method of distribution appears likely to supersede most of the continuous-current systems.

The alternating-current dynamos for working trans formers are generally excited, as before mentioned, by a small continuous-current dynamo Mr Mordey attaches this "exciter" direct to the large machine's shaft. This plan (although very convenient) may possibly have some disadvantages, as it does not allow of the speed of the exciter being varied. In the circuit of the exciting machine, *or in its own field-magnet circuit*, is placed a rheostat, by means of which the whole of the current can be varied. By these means the output of the alternator is to a certain extent under control. The alternator gives only alternating currents, collected off two plain rings revolving with the shaft (p. 99).

*Compound Dynamo in Incandescent Lighting.*—We have seen (p. 209) that a compound dynamo consists of a shunt machine to which a few turns of series winding has been added in order to compensate for the slight fall of potential due to the switching in of additional lamps. It is clear that if the number of lamps was always the same, a shunt-wound machine would prove all that could be desired for incandescent lighting, but such cases are extremely rare. Continuous current compound machines have proved themselves perfectly adapted for installation working, where all the lamps can be worked off one dynamo, as in ship lighting. They call for no regulation. A well designed compound machine, in which the magnetic circuit has low reluctance (and is therefore of wrought iron) should be capable of withstanding the following test. With one hundred lamps across the mains, all fully lighted up, any number of the lamps may be switched off without in any way affecting the remainder. Or, ninety-nine of them may be cut out without the change being visible in the hundredth. The same process may be reversed: one lamp may be burning across the mains, and ninety-nine more may be switched in at once without the change being appreciably apparent in the single lamp.

Another method of controlling the E.M.F. of a compound-wound dynamo is frequently employed for special purposes. The machine itself works as a shunt dynamo, the series winding being in the circuit of a separate smaller dynamo. This current is regulated either by hand or by some automatic device.

There are still other methods and combinations, but they belong more to experimental regulation than to everyday practice.

*The Shunt Machine in Electric Lighting.*—In incandescent lighting on a large scale, when continuous currents are used, as in Edison's system, the shunt method is preferred, and it is controlled chiefly by hand regulation, which has hitherto been found more trustworthy than any automatic device. Edison includes a rheostat in the shunt circuit, the resistance of which can thus be varied to suit the requirements of the work upon the mains. But shunt dynamos in incandescent lighting have a considerable range of self regulation, and in many cases where the load does not vary considerably they are used with perfect success. Where, however, a large number of fresh lamps are switched in, there is a call for current; this is at once supplied, because the act of switching in fresh lamps in parallel is to reduce the external resistance, and a larger proportion of current flows in that division of the circuit. But this increased flow causes a drop in the E.M.F., which is not easily recovered by the dynamo at a constant speed. If, however, there be means of varying the resistance of the shunt the exciting current may be slightly increased. In cases where the shunt machine is found to regulate itself within wide limits it will always be found that the armature resistance is *extremely small*. A shunt machine with a considerable resistance of armature is always a failure in point of self regulation on parallel circuit working. Shunt machines, having considerable self induction in the long magnet coils are very sensitive to inequalities of driving, and call for a constant speed.

*The Series Dynamo in Arc Lighting.*—The running of arc lamps in parallel has not proved practically economical, and in point of expense of energy cannot be compared with series running. While in the parallel systems of incandescent lighting the *potential* has to be kept constant within very narrow limits, in series arc lighting the potential will vary according to the number of lamps, but the *current* (usually of ten ampères) must be as nearly constant as possible. Numerous attempts have been made to render dynamo machines self regulating for constant current, but so far without success, unless we include the admirable exterior device of shifting the brushes used by Professors Thomson and Houston, and by Maxim, and a few other regulators of the same nature. But this is a different thing from self regulation by means of exciting coils, as in a compound machine. What is required in series arc lighting is such arrangement of the windings as will enable the machine to give the same number of ampères, whether there be one or many lamps in circuit.

Series wound dynamos are preferred for arc lighting. They are less sensitive to inequalities of driving than shunt machines. The first experiments in street lighting by means of continuous currents were made with series machines, and it was then thought impracticable to work more than one lamp from one dynamo. If, however, means are employed to maintain the current constant, it has been shown by Brush and Professors Thomson and Houston that a large number (sometimes exceeding fifty) can be successfully run in a single circuit. Street lighting by arc lamps is generally worked in this way.

## CHAPTER XVIII.

## *OPERATIVE NOTES.*

*In Erecting* large dynamos the magnetic joints must be made as perfect as practicable. The surfaces must be clean and "fairly" bolted, so as to come into general contact. Dowel-pins are generally furnished in such joints, and also in the basis of the bearings, so as to ensure proper alignment. Warping of castings may occur by reason of unequal foundations. This is a very bad fault. Warping may, however, be caused by the bolting down of other parts than the base. In erecting it is best to observe the rule that no two portions of the ironwork are to be forced into contact by means of bolts or nuts. Joints should lie perfectly "fair" prior to bolting. Foundation-rails, or belt-tightening rails, must be very carefully levelled, and free from warping throughout their length.

*Alignment of Bearings.*—Bearings of axis, if not dowelled into alignment, must be so set that the periphery of the armature occupies an exactly central position in the armature chamber. On no account must the armature be allowed to touch either of the pole pieces. The shaft should not only turn quite freely by hand, when the boxes are bolted down, but should be allowed an end-play of at least one-fourth of an inch. This assists in distributing the oil. As the armature shaft becomes heated in working it must not be fitted quite full into the boxes, otherwise the expansion will cause binding. The boxes should have spiral oil-distributing channels cut in them, or at the least one longitudinal channel in connection with the lubricator.

*Handling of Armature.*—Armatures admit only of the most careful handling. They should be lifted by means of the shaft, and in no case rolled over a floor. Brush brackets must be properly bolted together in the order generally indicated by figures stamped upon them, care being taken that the insulating sleeves, washers, or thimbles are put in their proper places, Brushes should be trimmed square, so as to bear equally upon the collector drum. They must be free from twist, which might cause them to bear upon the bars with one corner only. The touch must be flexible, and not too heavy. One of the most frequent causes of the destruction of commutators and collectors is the too heavy touch of the brushes.

Collector bars are now generally made from lengths of copper or phosphor-bronze, *hard drawn* to section. Such bars will withstand a heavier touch than those of soft *cast* copper.

When in work a new collector should be frequently wiped free from copper dust, and lightly touched with vaseline, or a mineral lubricant, until it acquires the hard, burnished surface which practically eliminates the chance of further wear. The best compound dynamos are now made so perfect that there is no sparking at the brushes, so that mechanical wear is the only matter to be looked after. Attrition, or dry cutting, is always due to a heavy touch of the brushes, and to allowing copper dust or grit to accumulate beneath the point of contact, and to the want of lubrication.

"*Connecting-up.*"—Connecting of the coils and brushes and terminals will depend entirely upon the nature of the machine. A series dynamo is very easily connected. Shunt and compound machines have their connections arranged as in the diagrams on pp. 47 and 50.

*Polarity of Core.*—When a dynamo is first started a strong current is passed through its field-magnet coils, in order to impart to the core a certain polarity, and leave therein a certain residual magnetism. It is upon this feeble magnetism that the machine begins to excite (p. 13); and because it is feeble it is easily destroyed by knocks, or it may be reversed by accidental contact with other magnets. In such a case the dynamo will either fail to excite or will give a current in the wrong direction in relation to the terminals, which are usually marked + and −, or indicated by the − screw being blackened. Complete failure of the residual magnetism is rare, but in such a case a sufficient current must be passed from some other source. A few accumulator cells, or the current of another dynamo, may be employed for this purpose; but failing both of these, as in the case of the faulty dynamo being situated away from powerful sources of electricity, a few large cells of the ordinary bichromate battery should be used. The massive cast-iron pole pieces of dynamos or the cast-iron yoke of the field magnet may generally be relied upon to retain sufficient magnetization.

In "connecting up," as it is termed, some difficulty is frequently experienced by beginners in determining the proper *course* of the current, so that it shall correspond with the direction of rotation and the marked direction of current from the terminals. In such case it is best to ascertain, first, the polarity of the field. This can be done with a pocket compass, or a very small bar magnet, for a N. pole will repel a similar pole, according to the law of magnets. Many rules are to be found in text books for finding the relative direction of the polarity and the current. If, however, we pick up an ordinary screw-bolt and look at it, end on, that extremity will be a S. pole, if we suppose the current flowing from us, in the direction of the screw. The course of the windings upon the magnet are easily traced, and the connections made accordingly. The best dynamo builders take care to mark all the terminals with letters or figures, so that A and A would be connected together, and similarly with B and B, or 1 and 1 or 2 and 2, and so forth. In making connections a good contact must be ensured, and the set screws made sufficiently tight. Connectors are not generally insulated, so that they must be kept well away from field coils or any of the metallic work.

In alternators there is no + and –, so that it is not of any consequence to which of the two collector rings the beginning or end of the coils is attached. The field magnets in these being separately excited, do not require residual magnetism for starting, and it is generally of no consequence in which way the current flows around them. The "direction" of the current from any dynamo can be readily ascertained by means of a pocket compass. The operator (facing north), standing with his back to the machine, places his compass *under* the leading wire. If the current is flowing *from* the dynamo in that wire the N. pole of the compass will turn to his *left* hand. It is assumed th the normal position of the needle, when out of the infl ence of the current, is parallel to the wire to be teste

*Belting.*—Before measuring for a belt, let tl dynamo be screwed *upon its slides*, as near to tl engine or driving pulley as they will allow. Tl belt should have an inch of width per horse-pow (which is only applicable for moderate powers) to l transmitted, if running at 1,000 feet per minute. F dynamo work *thin*, flexible belting should be use and it should have a butt joint, and in no case lap joint. The butt joint may be made with ar of the metallic fasteners, but a well arranged lacir is to be preferred, and is more flexible. New beltir stretches very much, and gives a great deal of troub until it settles down to its work. For this reasc new belts are generally stretched beforehand, or ru upon the machine for a time for this purpose. Tl dynamo is moved away from the driving pulley tighten the belt, by means of the slides. Slight sl of the belting, when new, is unavoidable. The be must not be too tight.

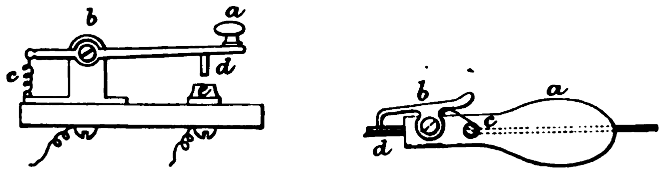
*Rope Driving* is coming rapidly into favour f dynamos of considerable size, a single or multiple ro being used upon a multiple grooved pulley. The are several advantages in this method of driving, ar there is less liability to loss by slipping, or stoppa by the belt coming off the pulley.

## Faults.

*Ground.*—A great many of the common failures dynamo and circuits connected therewith are d simply to ground contact of the machine. Althou it is assumed that the electrical system is carefully insulated from the ironwork of the dynamo, yet an accidental contact may occur. If the ironwork be completely insulated from earth this fault need not extend beyond the dynamo itself (it will greatly weaken its total insulation). If there be "ground" contact the evil extends to every part of the electrical system, and in some cases practically halves the insulation of leads. Dynamos are sometimes only insulated from earth by being placed upon dry wood battens. A large sheet of vulcanised fibre is better, which, however, need only be placed beneath such parts as touch the foundation. Holding down bolts have sometimes tubes of fibre placed over them, and washers of an insulating material beneath the iron washer of the bolt, or its nut, so as to insulate the bolt from the ironwork.

Testing for ground is very simple. The apparatus consists of a galvanometer, a source of current, and a few yards of wire. The source of current used in a dynamo room usually consists of a few secondary cells. The stronger the current the better. A circuit is made by first getting a good "earth" contact (water or gaspipe) connecting to that, thence to the source of current and the galvanometer in series. A wire from the remaining terminal of the galvanometer is thus to be brought into metallic contact with the ironwork of the dynamo. If the current is of some strength, and there is a ground contact, it will of course be indicated by a deflection of the galvanometer. If contact between the electrical system of the dynamo and its ironwork be suspected, it can easily be ascertained by making a circuit from the ironwork, in series as before, and touching with the testing wire the terminals of the field-magnet coils and the brushes.

Instead of employing the crude and unsatisfactory device of touching two wires together in making



Figs. 77 and 78.—Two Forms of Circuit Closer for Testing Purposes.

contacts in testing and other work, it will be found advantageous to make use of a simple form of "key" or circuit-closer. Thus in Fig. 77 the key may consist of a tapping lever, *a*, jointed at *b*, and held up by an antagonistic spring, *c*. The contact takes place at *d*, upon the copper block *e*. The connections to the metallic parts are as represented. The key is mounted upon a dry wooden base, with *large* termina screws or clamps, wide enough to receive the extremity of a cable of considerable size. In Fig. 78 is represented a portable or "one-hand" circui closer, which will be found convenient in making contacts when the other hand is engaged in switching or attending to instruments. The handle *a* is fitted with a trigger contact, *b*, controlled by a spring, *c*, the contac taking place at *d*. For reversing purposes the simple reverser, exhibited in Fig. 79, will be found

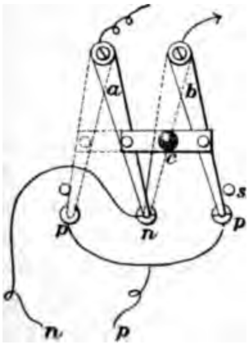


Fig. 79.—Current Reverser for Testing Purposes.

very useful. Levers *a b* are worked as one by the bar *c*, on and off the studs *p n*. The reversed position is shown in dotted lines. All the parts should be heavy, and of massive construction.

To localise the fault is not so simple. It can only be done by determining, first, whether the field coils are in contact. This can be settled by disconnecting them from the armature circuit and from each other. In this way the fault can at least be attributed to the armature, or to one of the field coils. A contact of one of the coils can generally be easily rectified, but a fault between the armature windings and its core is a more serious matter, and may involve the removal of all of its sections. These contacts generally occur in armatures in which the core plates have become loose, and have cut through the insulation, and to other faults of construction. It may be pointed out that broken circuits in the armature are generally due to a rupture between a coil section and a collector bar. In some of the earlier dynamos the coils of the armature were not "mechanically" driven; they were merely wound upon the core, and bound down in the usual way. Alternate heatings and coolings soon cause a looseness here, and the tangential drag of the field pulls the coils out of their former position slightly, but sufficient to cause breaks with the collector extensions.

But short circuits are far more troublesome than dead breaks. A short circuit between two coils of a drum armature can be ascertained as follows: Make contact to one segment of collector; endeavour to get a deflection of the galvanometer by touching all the other segments in succession. If there is contact between that coil and any other it will soon be found.

If there is no contact only the corresponding bar of the same coil will give a deflection. Each section can in this way be tested in turn. A coil that is short-circuited will be apt to be *burnt out*. The current, instead of flowing into the external work, will circulate continuously in the coil. It will become heated, and finally its insulation will be burned. Such a fault is generally indicated by some abnormal sparking at the brushes, and by a dimming of the light or falling off in the current. A short circuit outside the machine will, in a series-wound dynamo, speedily destroy the whole of the insulation by casting an abnormal current in both armature and field coils. Care is necessary, then, to avoid short circuiting of such machines, even for a short time. The driving belt can generally be thrown off the pulley of a series machine by momentarily short-circuiting it, and this shows the abnormal load created.

Shunt machines cannot easily be injured by short circuiting. If a wire be put across the terminals such a machine will not readily excite itself, and it will give no current. When a moderate resistance is in circuit the current will be in proportion. This is due to the fact that whatever current is generated finds its way through the low resistance, across the terminals, and that there is, in consequence, little or no current flowing in the shunt, so that the field magnet is not excited. But a dynamo should never be connected to a doubtful resistance or one of unknown value.

*Distributing Station Leakage Test.*—In a central station large currents are dealt with, and an earth leakage from any of the mains becomes a serious source of loss or other trouble. In the case of low potential dynamos a lamp test is in common use for the detection of ground leaks. Two incandescent lamps of a voltage as high as that of the dynamo are connected in series from one terminal of the machine to the other. An earth contact is made from the wire *between* the two lamps. If there should be a leak to earth one of the lamps will be brighter than the other. The brighter lamp will show not only to a certain extent the nature of the leak, but it will indicate the particular leading wire in which it is to be found. Its superior brightness may be regarded as due to leakage to earth from the leading wire to which it is connected. This occurs by reason of the earth portion of circuit provided between the leak and the intentional earth contact between the lamps.

### Failure of Dynamo to Excite or Start.

When a series-wound dynamo fails to excite or yield a current, the inference is that the external portion of the circuit *presents a very great resistance.* Now this may be due to several causes. Provided the armature circuits and insulation are intact the fault should be looked for, first, in the brushes. They may not be in proper contact with the collector bars. The collector bars themselves may be short-circuited to each other. Between the bars there is interposed a layer of insulating material. If this should be of a nature that will readily absorb copper dust from the commutator, as *asbestos*, or *fibre*, or *wood*, it will speedily become conductive. The *mica* insulation of collectors is now, however, so common that this cause of failure is extremely rare in new dynamos. But some of these are insulated by air-gaps only, and these interspaces are apt to become bridged across by a paste of copper dust and oil. Although many persons suppose that *dirty* contacts, or merely oxidised brass contacts of brushes with their brackets at terminals, &c., of a dynamo are sufficient to account for loss of current, yet that is seldom or never the case in practice. But it may well occur that brushes have been so badly looked after that a tough film of oil-gum covers them all over, and that their connection with their slides is anything but perfect.

With the external portion of the circuit we are scarcely concerned here, but as the fault of non-starting may be attributed wrongly to the dynamo, it may be pointed out that faulty contacts are likely to occur at fusible safety plugs fixed for safety near to the dynamo. These very frequently consist of lead wire, bits of which are interposed between pairs of terminals.* This arrangement is most unsatisfactory. It is not practicable to get a good contact with a lead wire in an ordinary binding terminal. If pressure be applied the wire becomes flat, and its section is greatly reduced. It speedily oxidises, and finally burns out, at the contact point. If lead wire is to be used it should be soldered into bits of thin brass tubing at either end, so as to afford a hard touch for the terminal screw.

*Ribbon Lead* is much to be preferred, as it can be clamped with a wide surface between two flat plates of a terminal. Failing the discovery of the fault near to the machine, it must be looked for in the external portion of the circuit beyond switches and cut-outs. Whether the fault really lies within the machine—that is, within its terminals—can be readily determined by momentarily short-circuiting it. This is most safely done by fastening one end of a few yards of wire in one of the terminals, and bringing its opposite end against the other terminal—but only for an instant. If the machine is excited, a bright flash will mark the break of contact from the terminal; sparking will also be shown at the brushes during contact.

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* The Phœnix Fire Office rule provides for a fusible cut out upon each wire close to the dynamo.

*Failure of the Residual Magnetism* is very rare, but it may occur, and it is worth while testing for it before troubling to take the dynamo apart for further examination. If there is no appreciable residue of the magnetism at the pole pieces it will be apparent by their failing to attract a piece of iron. This kind of failure is generally due to some opposing current circulating in the coils while the machine is idle, as may readily occur in the case of a dynamo used for electro-deposition or for charging secondary batteries.

These observations apply, in many points, to the case of shunt and compound machines. But a shunt machine will not, as we have already seen, readily start upon short circuit. Hence, what would constitute a resistance small enough to ensure the destruction of a series machine will, in many cases, fail to induce a shunt machine to excite and give a current. To "build up" a shunt machine, then, a certain proportion must be observed between the shunt coils and the interpolar wire.

*Point of Best Collection—Position of Brushes.*—But in any kind of continuous-current dynamo failure to give a current may be due simply to the brushes having accidentally become shifted from the proper collecting line. In most machines the brush rocker is capable of being moved a certain number of degrees upon either side of this line. In starting a dynamo the brushes should be set in the most advantageous position. This will generally coincide with the line of least sparking. The brushes cannot usually be properly set until the normal resistance (work of the dynamo) has been put in the circuit. If the brushes must be set without this assistance they will not be far off correct by being placed slightly in advance—in the direction of rotation—of a line passing through the field at right angles to the lines of force (drum armatures).

*Worn Collector.*—Unless the armature be very accurately wound, and equalised electrically, there will be unequal sparking under the brushes. This will result in burned spots upon certain collector bars. These "spots" are very troublesome in some machines. They regularly occur upon the same bars. This shows some defect in the coils attached to these bars. But once a spot is started, from whatev
cause (as the careless practice of lifting the brus
while the machine is giving current), it will g
deepening, and there is no remedy but tur
the collector in the lathe. When the coll
comes grooved, out of round, or patchy,
burned into its surface, it must be re-
lathe. The file is no remedy for a f
nor should emery cloth be brought
time. The emery crystals can b
microscope to become bedded i
the part of an emery wheel
use of various powders has
order to reduce friction.
as effective as any.

In the case of larg
turning the collector

from the machine is steadily on the increase. The ordinary speed of the dynamo is, however, in most cases, much too great for this purpose. It is necessary to move the armature as slowly as possible. In many cases it is practicable to run the dynamo slowly as a motor, by passing a current into it while re-turning the collector bars. In any case a slide-rest is usually considered requisite, which is generally arranged so that it may be bolted to the ironwork in position for the work required. Collectors are, however, very frequently re-turned by hand by the aid of an ordinary brass turner's round-nose tool, or a graver-pointed tool. In this case it is only necessary to provide a rest for the tool, and a stiff bar or bracket, bolted to the brush rocker is, in many cases, found sufficient for this purpose.

*Overloaded Dynamo.*—In the case of a compound dynamo it may well occur that too much work may be demanded of it. If the machine is carefully "compounded" its E.M.F. will rise rather than fall at or near full load. Hence it sometimes happens that too many lamps are put upon such a machine. The first sign of overloading is sparking at the brushes. A really good compound machine should show little or no sparking up to full load. Long sparks are followed by rapid heating of the armature and field coils. This may go on until the insulation gives out, or the belt slips off the pulley. In a properly regulated station this condition would never be attained. The ampèremeter denotes the rise in the current, and a fresh machine is brought up to full excitation ("built up") and switched on, taking half the work. Details of the working will be found in Chap. XVI.

## CHAPTER XIX.

### *ELECTRO-DEPOSITING DYNAMOS.*

DYNAMOS intended for the work of electro-plating and for the reduction of ore are a class apart. They are distinguished chiefly by being arranged for low tension and large current working. Thus, while dynamos intended for electric lighting and the transmission of power very seldom develop less than fifty volts of electromotive force, those built for electrometallurgy seldom attain a voltage of ten. This peculiarity is due to the fact that electro-depositing baths present very little resistance, and that the rate of deposition is regulated entirely by the current and not by the electromotive force.

Persons engaged in the work of electro-deposition still appear to cling to the antiquated notions of the nature of electricity held many years ago. The march of progress in electricity has, however, shown the advisability of employing more exact and correct terms and methods in dealing with the output of dynamos. Thus the old term "intensity," no doubt in its best sense, implied what is now more correctly called electromotive force. But intensity was an unknown quantity, whereas electromotive force is asily expressed in volts. The real significance or agnitude of the *volt* can be roughly apprehended by remembering that it is equal to the "intensity" of two ordinary Smee's electro-depositing cells connected in series.* "Quantity," on the other hand, meant what is now called current, and as current it can be expressed in the unit, *ampères.* Instead of saying, according to the old style, that a square foot of work in the bath required a quantity of electricity equal to that evolved by five one-gallon Smee cells, it is now said that the current required is ten ampères, under an electromotive force or "pressure" of two or three volts. These figures are illustrative only.

In order to exemplify the nature of the work required of dynamos intended for electro-deposition it will prove useful to give, in tabular form, the "pressure" or electromotive force usually called into action in the dynamo working of the ordinary solutions. These values, although derived from practical working, depend, however, as every plater knows, upon the distance maintained in the vat between anode and the articles being plated. They also may vary somewhat according to the conductivity (or in many cases acidity) of the solution being worked.

ELECTROMOTIVE FORCE AT TERMINALS OF THE PLATING VESSEL.

| Solution of | "Pressure" in Volts. |
|---|---|
| Copper for plating . . . . . | 0·6 to 0·8 |
| Copper for electrotype . . . . | 0·5 to 0·7 |
| Copper cyanide for iron . . . . | 4·0 to 8·0 |
| Silver for ordinary plating (double cyanide) | 1·0 to 3·0 |
| Gold (ordinary) . . . . . . | 0·5 to 1·5 |
| Nickel (double sulphate) . . . . | 4·0 to 6·0 |
| Brass (cyanide) . . . . . . | 5·0 to 7·0 |
| Tin . . . . . . . . | 0·5 to 1·0 |

Current, on the other hand, refers to surface being plated, so that we speak of a *current density* of so many *ampères per square inch or foot.* With reference to ordinary plating and depositing, we may represent the practical working values as follow, according to the rate of deposition desired:

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* The average E.M.F. of a Smee cell is 0·47 volt.

CURRENT DENSITY (OR AMPÈRES) PROJECTED UPON THE CATHODE.

| Solution of | Ampères per sq. foot. |
|---|---|
| Copper, acid bath | 5·0 to 10·0 |
| Copper, cyanide bath | 3·0 to 5·0 |
| Silver, double cyanide | 2·0 to 5·0 |
| Gold, chloride in cyanide | 1·0 to 2·0 |
| Nickel, double sulphate (nearly neutral) | 6·0 to 8·0 |
| Brass, cyanide | 2·0 to 3·0 |
| Tin | — — |

Thus, the *superficial area* of the work, and not the "number of gallons in solution" as formerly, is the matter to be considered in determining the ampères or "quantity."

We cannot here trace the successive historical steps in the evolution of the depositing dynamo, but it may be mentioned that very shortly after Dr. Faraday's discovery of electro-magnetic induction previously referred to, Mr. Woolrich, of Birmingham, obtained a patent* for a multipolar dynamo intended for electro-plating. The machine consisted of a disc armature, carrying bobbins with iron cores. The field magnets were of steel, of the horseshoe type, arranged in a circle. This machine, which appears to be the first of its class, was shown at the Electrical Exhibition held in Birmingham in the autumn of 1889. It was constructed for the firm of Messrs. Prime, in whose works it had been usefully employed for a number of years. Wilde's magneto machines, having Siemens shuttle armatures, were introduced later, and had an extensive application. Mr. Wilde has also employed his multipolar dynamo for copper deposition on calico-printing rollers. These were followed by Weston's and other American dynamos, and by the famous Brush machine.

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* Specification of Patent, No. 9,431, 1842.

The first practical application of dynamos was in connection with electro-deposition. The introduction of electric lighting, which began to assume importance about 1880 gave a great impetus to the improvement of dynamos, with the result that at the present time all of the earlier electro-plating machines have been superseded by later forms, better adapted to the purpose.

*Gramme's Machines* have been, and are still, used extensively on the Continent in electro-deposition. Since it is necessary to keep down the resistance, the ring core (p. 100) is wound, not with wire, but with copper strip in several layers connected in parallel or as a single turn around the armature. In addition to this, the adjacent pairs of sections are, in some machines, connected in multiple. This has the effect of halving the resistance of the armature. It reduces the electromotive force (or volts) to one half, and doubles the current or ampères. But, obviously, a common resistance of winding in the field magnets is not admissible in machines of low armature resistance. Hence, the Gramme fields are wound with rectangular copper rod, of considerable sectional area. Great heat is developed in any connecting wire in the circuit of these low resistance dynamos if its section is not considerable; hence, collector bars, brushes, brackets and terminals, are all constructed either of gun metal or of copper, and of a thick, heavy pattern. Thick copper straps are used to connect the dynamo with the vat or vats. In Gramme's large machines, built for copper refining, the forty sections of windings of the ring are divided into two twenties, each of which has its own collector and pair of brushes. The collectors are placed one on each side of the armature, and the pair sections (of twenty coils each) can either be connected in series, to yield an E.M.F. of sixteen volts, or in parallel, which doubles the current to over a thousand ampères, and reduces the volts to eight. In copper refining the vats are frequently worked in series, necessitating double the electromotive force stated in the above table. The machines are series wound.

### Secondary Current of the Plating Vat.

It is well known that an electrolytic bath acts to a limited extent as a secondary battery or accumulator. If a current be passed in such a bath, it may be shown to act as a battery, sending a reverse current through a galvanometer as soon as the plating current is stopped. This was a source of great trouble when dynamos were first used for deposition. The objection did not, of course, apply to the early magneto machines having permanent magnets, as will be shown. But a series-wound dynamo presents a different set of conditions. If such a dynamo were to feed a vat, and the engine driving it were to be stopped, the dynamo current would, of course, fall off. But a reverse current would be immediately liberated from the vat. This *secondary* current would flow around the dynamo circuit and speedily reverse the feeble residual magnetism of the field. If this were not detected the dynamo, when next started, would, in consequence, *yield a current in the wrong direction.* Disastrous effects would follow: the articles to be plated would become the anode and would begin to dissolve, while the real anode, which is intended to dissolve, would receive a deposit.

An accident of this kind might occur without the stoppage of the dynamo. If the current flowing from it were feeble, if it were doing a small amount of work, it might happen that the vat current would prove sufficiently strong to overpower it, and so reverse the feeble magnetism. But this latter contingency would probably be rare in practice.

To obviate these occurrences, several inventions were brought out by dynamo makers. Weston devised a centrifugal contact-maker. This kept the machine's circuit closed, as long as its armature was in motion. When the machine was stopped, the contact was automatically broken.

### Brush's "Teazer" Winding.

Brush, however, took a far more important step, and this, no doubt, without knowing that in the near future it would prove a most important auxiliary in the supply of electric light. He wound the magnets of his dynamo, under the main coils, with a coil of fine wire, connected as a shunt across the main circuit. This highly-resisting path drew a small percentage of the total current around the magnets. If the main circuit were opened, this shunt winding would obviously draw a current from the armature and maintain the polarity of the field. But Brush's object was to maintain the electromotive force constant, under great variations of load. No series wound machine can do this; nor is a simple shunt wound machine entirely satisfactory. When, however, the series winding is combined with the shunt, forming what is now called compound winding

(p. 49), a practically perfect and automatic regulation is effected. That is to say, whether the superficial area of the work being plated is large or small, the pressure or volts is maintained at a given value. The conditions are almost identical with those of parallel electric lighting. Most dynamo builders, producing machines for electro-deposition, have followed Brush in adopting a compound winding.

### Baths or Vats in Series.

For the large operations of refining or depositing copper or other metals from solutions of their ores—processes which are now carried out electrolytically on a very large scale—the Brush Company prefer to use the "Victoria" dynamo, machines wound to give such current and electromotive force as to render them not very dissimilar to the lighting machines of the same type. In this kind of electro-deposition it is found better to use a number of baths in series, instead of the old arrangement of placing them all in parallel. The latter plan, although it has some conveniences, requires excessively heavy conductors for large work if it is desired to avoid loss of power.

It is obvious that in order to work several baths in series the electromotive force must be considerable, and large dynamos for this special purpose are frequently capable of exerting a force of fifty or more volts. In a recently-introduced dynamo, constructed by Messrs. Elwell Parker, and wound specially for heavy ore reduction, the pressure is 50 volts, with a current of 500 ampères at a speed of 450 revolutions per minute. The machine is of the four-pole type with the usual drum armature. The diameter of the latter is 22 inches, by 20 inches in length. There are

80 wires in the circumference, each having a section of 0·2 square inch, the density of current in the conductors being 1,880 ampères per square inch. The length of active conductor is 1,600 inches. This gives 8 inches per volt at the peripheral speed of 2,500 feet per minute. The ratio of the active to the total length of wire on the armature is 47 per cent. The field magnets are shunt wound.

*Electro Copper Ore refining.*—Although not strictly within the scope of these pages a few words of explanation of the nature of the process used in purifying copper by the current from these dynamos may not be entirely out of place. Slabs of crude copper ore are used as anodes in a series of vats, the receiving plate or cathode being pure copper in the form of a thin sheet. The solution generally used is that of sulphate of copper, saturated. The same solution flows through all the vats in order to keep its composition uniform. The pure copper is deposited upon the cathodes, which are replaced from time to time. The insoluble residue which drops from the anodes frequently contains, among other metals, gold, silver and tin. When the electrolyte becomes very impure, chiefly by reason of admixture of sulphate of iron, it is evaporated, and the crystallised foreign matters separated from the copper solution.*

*Siemens' Dynamo in Electrolysis.*—Messrs. Siemens have constructed some very powerful dynamos for this purpose, in which the ordinary armature wires

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* See Mr. Elkington's Specifications of Patent, No. 2,838 of 1865, and 3,120 of 1869. This process is carried on very extensively on the Continent, and in England at Messrs. Lambert's and Messrs. Elliott's at Swansea (fifty tons deposited per week), and at numerous smaller works. In America the Bridgeport Copper Company refine over one hundred tons per week.

(p. 163) are replaced by massive copper bars, so that the resistance of the armature is almost inappreciable. In the ordinary Siemens machines when wound for electro-plating it is usual to connect the windings four or eight in parallel, so that each section of the armature really consists of but one turn of conductor. This reduces both the E.M.F. and the resistance to the required extent. By means of these large sized dynamos the electrolytic separation of copper is carried on very extensively in the Hartz district, and especially at Oker, at Moabit, Berlin, and elsewhere in Germany.

One of the leading features of the electro-depositing dynamo is its adaptability for slow speed working. The low pressures required do not demand a high speed. This, in itself, renders the dynamo very durable and easy to manage.

## CHAPTER XX.

## *TYPICAL DYNAMOS.*

THE production of dynamos, and the number of forms given to them, is now so immense that it is no longer practicable or needful to attempt to give an account of every maker's machines. Nor is it desirable to weary the reader with lengthy descriptions of particular dynamos that have become obsolete, or have in great part been superseded by more efficient forms. It is proposed, therefore, in the present chapter, to select a few typical machines, representative of present practice, for particular description; and only to mention (necessarily briefly) many excellent machines already fully described elsewhere, and by other writers. But it should be clearly understood that in selecting a few machines produced by particular makers, as *examples*, in order to make the subject clear to the reader, this course implies no understanding that these typical dynamos are necessarily considered by us superior to other dynamos not mentioned, or only briefly touched upon.

It will be convenient to commence by dividing the machines into two classes, *continuous current* and *alternating current* dynamos. This division is the more necessary because the two kinds of machines differ usually in their construction as well as in the nature of the currents evolved by them.

### Typical Continuous Current Machines.

The rise of electric lighting may be said to be coincident with the production of the dynamos of Gramme and Siemens; and we may, therefore, mention these first, merely touching upon the earlier forms, however.

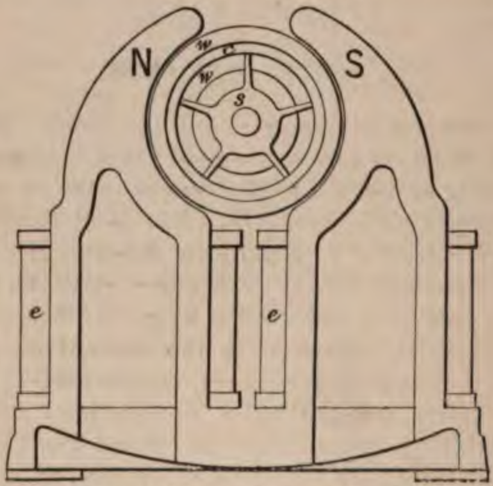

Fig. 80.—Diagram of Gramme Dynamo. (Type Superieur.)

### Dynamos of the Gramme System.

The nature of the early types of this machine, with the well-known ring armature, revolving between two "consequent" poles of a pair of field magnets, combined, has been frequently described at considerable length.*

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* See the Author's "Electric Light," 4th edition, pp. 74—97.

The latest form adopted by Gramme belongs to the "overtype" (called "type supérieur"), depicted diagrammatically in Fig. 80. It consists of an inverted two-pole field magnet, having a Gramme armature mounted between the poles. The bed plate, bearing standards, and field magnet core and pole pieces are usually cast in one piece. The magnet limbs are cast hollow, but have a sufficient sectional area. In Fig. 81 is depicted, in section, the armature and its arrangement upon the shafts. The later armatures constructed by the Société Gramme are a great improvement upon the early rings, which were generally centred upon a wooden hub. The "type supérieur" is constructed in different sizes. A small machine, intended for separate installation lighting, has the following dimensions :—

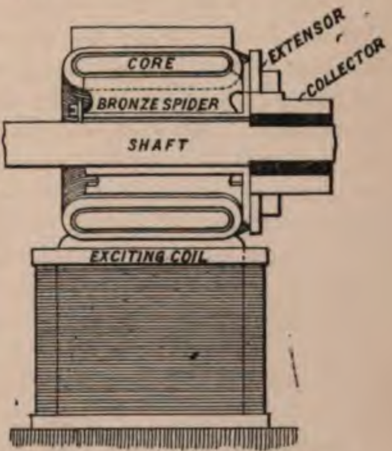

Fig. 81.—Section of Gramme Dynamo. (Type supérieur.)

Sectional area of each magnet core 174 square centimetres; length of the magnetic circuit within the magnet, 81 centimetres; area of each polar surface, 366 square centimetres; shunt coils, resistance, 46 ohms; armature core—internal radius, 6·5 centimetres, external radius, 9·15 centimetres, axial length, 16 centimetres, total sectional area, 80 square centimetres. Number of windings in the ring, 300; resistance, 0·174 ohm; commutator bars, 60; output, 40 ampères at 110 volts; speed, 1,400 revolutions per minute.

The Gramme system has received considerable attention from electrical engineers in America, and the Fuller machine of this type is recognised as of a high order of merit.

### Dynamos of the Siemens System.

The earlier machines of this system are now so well known, or have been so frequently described,* that we may pass to the later improved form.

*Two-pole Type.*—Messrs. Siemens have built dynamos for the British Navy having a two-pole field magnet of the type depicted at p. 280 (Edison-Hopkinson dynamo), but of oblong section. The large machines furnished to the *Camperdown* ironclad are compound wound, run at 350 revolutions, and yield a current of about 300 ampères at 80 volts. They are driven direct by Brotherhood three-cylinder engines. A later type adopted by this firm for continuous currents is similar in every respect, except as to armature connections, to the Kapp machine represented at p. 287. In the Siemens ring multipolar dynamo the field magnet is internal and fixed, while the armature revolves around it.

*Alternating-current Dynamo.*—Siemens' multipolar machine for the production of alternating currents has been frequently described.† The firm have built various other forms of alternator.

### Various Dynamos.

*Sautter-Lemonnier Dynamo.*—A general view of the form given to the Gramme machine by these makers is given in Fig. 82. This machine is known as the "type industriel." Two of these dynamos were shown at the Paris Exposition of 1889. They had a capacity of 10,000 and 20,000 watts respectively.

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* See "Electric Light," 4th edition, pp. 113—121.

† See "Electric Light," 4th edition, p. 125.

The smaller machine has an armature 500 mm. diameter. It is wound with 210 turns of the conductor, connected to a collector having 70 bars. The resistance of this armature is ·02 ohm. At 1,000 revolutions it generates a current of 90 ampères under an electromotive force of 120 volts, and maintains alight 280 10-c.p. lamps, or 30 six-ampère arc lamps, the h.p. absorbed being 16. It is compound wound. The shunt coils measure 6 ohms, the series turns showing ·03 ohm. The weight of the machine is 850 kilos.; diameter of pulley, 250 mm.

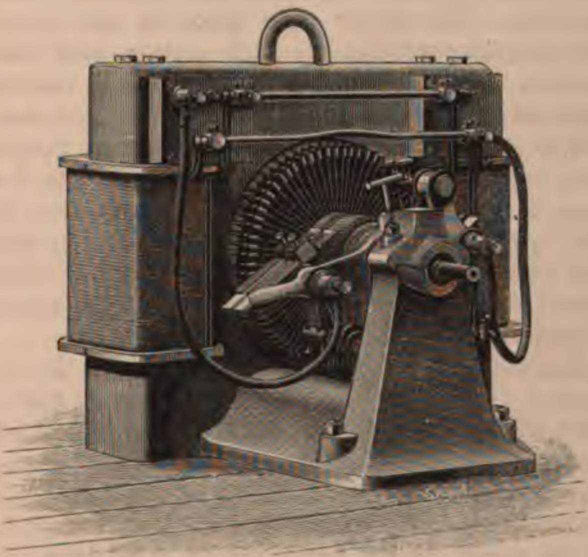

Fig. 82.—Sautter-Lemonnier Dynamo.

The larger dynamo has an armature 600 mm. in diameter. It is wound with 90 turns, connected to a collector having an equal number of sections. The resistance is ·003 ohm. At a speed of 850 revolutions per minute it evolves a current of 185 ampères under an electromotive force of 120 volts, and maintains 560 10-c.p. lamps, or 60 six-ampère arc lamps, the h.p. absorbed being approximately 33·50. The shunt coils have a resistance of 14 ohms, and the series turns ·004 ohm. Total weight, 2,000 kilos.; diameter of pulley, 375 mm.

In both machines the lower pole piece is cast with the base. The upper pole piece is cast separate. The magnet cores are of square section, with rounded corners. They are of a specially soft variety of wrought iron. Altogether, these dynamos may be said to stand in the front rank of French machines. They are compact in form. They generate a very intense field. The magnetic circuit is very short. The dynamo has a high ratio of output to weight. The same builders construct an eight-pole Gramme wound dynamo, which may be run at slow speed for central station work.

*Rechniewski's Dynamo.*—This machine is of the bipolar "overtype." The armature is of the drum form, with Pacinotti teeth, built up of iron washers. The star wheel driving the core has arms shaped so that they perform the function of a fan in drawing the air through the core. The magnet is remarkable in its cores, being built up of thin iron plates. It forms one of the very few laminated magnets in use.

*The Desroziers Dynamo.*—This machine, as shown at Paris, is of the disc armature type, and is chiefly remarkable in the method adopted in building the disc and its coils. The disc itself is of German silver. The coils are of the "pancake" shape. They are laid upon either side of the disc, and secured in a peculiar way by means of compressed cardboard. The armature is very thin—scarcely ¾ inch. The field magnet is composed of six alternate poles on either side, arranged as a double crown, as is now common in alternators. The poles have extension pieces. The armature being cross-connected, there are two sets of brushes placed 60° apart. They bear upon a Gramme collecting cylinder. The speed is 200 revolutions, and the current evolved in the machine shown at Paris had a strength of 14,400 watts.

*Dynamo of the Société alsacienne de Constructions Mechaniques of Belfort.*—The leading machines of this celebrated Company are of the bipolar overtype. They have drum armatures. These are constructed in several sizes up to the large machine, weighing five tons, with an output of 60,000 watts at a speed of 300 revolutions. The brushes used upon the collector are of copper or bronze gauze. The collector is composed of a special variety of hard iron. Its sections are overhung from a boss on the armature end, and have no support upon the other end. They are separated by air gaps only. The interior is hollow, except for the shaft, and the end left open. This allows of the falling away of any metallic dust, and assists in keeping the air gaps clear. The field magnets have wrought-iron cores, carefully fitted into the base and the pole pieces, and shrunk in position. The wrought-iron cores are allowed to project into the armature gap or chamber, and are cut away at that point to the required circular form. This Company also build a six-pole machine with external ring armature—a form becoming common on the Continent for slow speed work. The internal radial magnets are cast in one mass with the base. They are, therefore, fixed. The external ring armature forms a rim 7 feet 4 inches in diameter, with a width of 12 inches. The core is composed of sectional iron washers. It is carried by an eighteen-spoke star wheel of brass. The core is wound as a Gramme ring in 714 sections. The machine carries no collector at tho axis, as in ordinary dynamos. The speed being slow, it is practicable to collect the current upon the periphery of the armature itself, plates being provided for that purpose. In the machine exhibited at Paris, the armature made 150 revolutions per minute. The current evolved was 1,000 ampères at 125 volts, the energy being 125,000 watts. The driving power was a steam-engine of 150 h.p. Total weight of machine, about 7 tons.

### Brush's Open-coil Dynamo.

This celebrated machine has been so frequently and fully described* that we can only spare space to speak briefly of its peculiar connections from the armature, constituting an "open coil" arrangement. This implies the cutting out of the idle coils twice during each revolution. In the Gramme winding the whole side or half of the ring windings are constantly in circuit: in an open coil dynamo the really idle portions are short circuited by means of the commutator. If we instance the eight coil armature, it will be found that it really represents four separate twin-coil machines. These machines are each effectively similar to a Clark's armature of the early pattern, for each has its own commutator. The currrents are alternating currents until rectified by the commutator. But by means of a cross connection between the brushes the machines that are paired by the commutator are at the right moment brought into series. The connections are more fully considered at p. 147. The Brush machine has now several competitors in the work of feeding arc lamps. A miniature diagrammatic view of the Brush machine, front and end, is given in Fig. 83.

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* See "Electric Light," 4th edition, p. 148.

### Edison's Dynamo.

The latest improved form given to the Edison machine is that represented generally in Fig. 84. This particular type is due to Dr. Hopkinson, who considerably modified the earlier Edison machine, by improving its magnetic circuit. The dynamo will be seen to consist of a bipolar field magnet, having its pole pieces bolted to the foundation plate, a high footstep of zinc being interposed to obviate short circuiting of the magnetic lines. The armature windings arranged according to the method of grouping invented by Edison (p. 155). The figure represents a bar armature dynamo for incandescent lighting of low tension. The E.M.F. is 50 volts, current 1,000 ampères, speed 440 revolutions. The general dimensions are: height 68½ ins., length (axial) 69 ins., weight, gross 108 cwt.

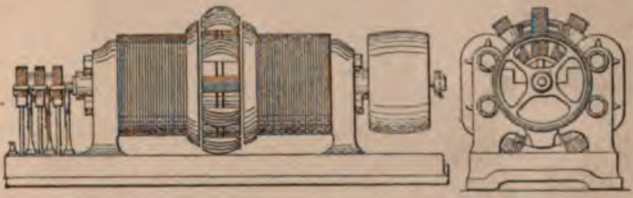

Fig. 83.—Diagram of Brush's Dynamo.

In another dynamo of this class, intended for an output of 320 ampères at 105 volts, at 750 revolutions, the field-magnet limbs were of rectangular shape, and were formed, inclusive of the pole pieces, of hammered scrap iron. The zinc footstep was 3 inches deep. The armature core was built up of 1,000 discs, magnetically separated by paper. Diamete of armature core, 25·4 centimetres; of shaft hole, 7·62 centimetres; o shaft, 6·98 centimetres; length of core, 50·8 centimetres; of field-magne limb, 45·7 centimetres; breadth, 22·1 centimetres; width (parallel t shaft), 44·45 centimetres; length of yoke, 61·6 centimetres, width, 48·

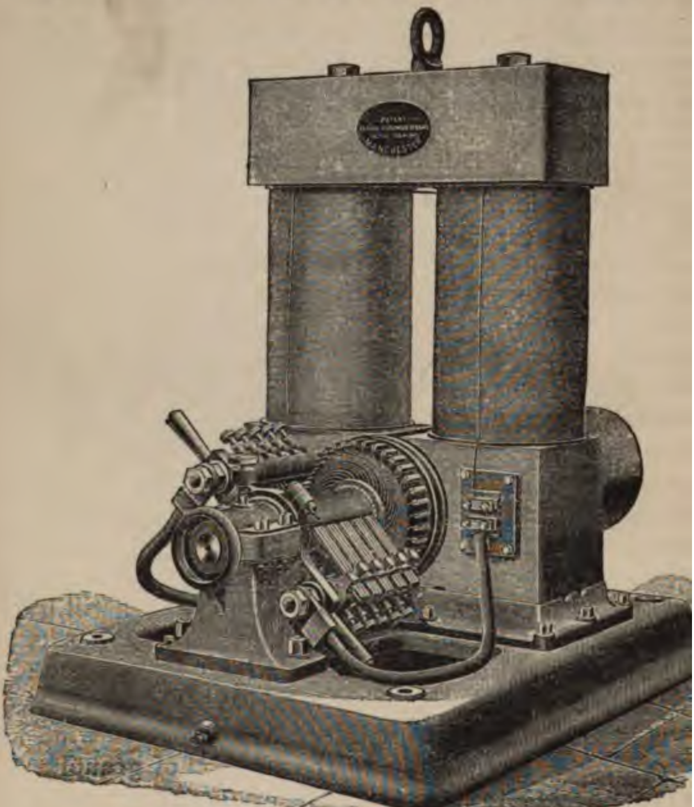

Fig. 84.—The Edison-Hopkinson Dynamo (English Type).

centimetres, depth, 23·2 centimetres; diameter of bore of field magnets, 27·5 centimetres; depth of pole piece, 25·4 centimetres; width, parallel to shaft, 48·3 centimetres; width between pole pieces, 12·7 centimetres; area of section of iron in armature core, 810 square centimetres; angle subtended by bored faces of pole pieces, 129°; actual area of pole pieces, 1,513 square centimetres; effective area, 1,600 square centimetres; thickness of gap space, 1·5 centimetres (air gap); area of section of limbs, 980 square centimetres; ditto of yoke, 1,120 square centimetres. The windings are as follows:—Field-magnet, 11 layers on each limb of copper wire, 2·413 millimetres diameter; number of convolutions, 3,260; total length, 4,570 metres. The armature is wire wound with 40 convolutions in two layers of 20 convolutions each. The wire is stranded, consisting of 16 strands, 1·753 millimetres diameter. Resistance: field magnet, 16·93 ohms; armature, 0·0009947 ohm. Magnetizing current, 6 ampères, commutator 40 bars of hard copper with mica insulation.

If the windings of the armature were connected directly to the collector bars, the position of the brushes would be upon a diametrical line at right angles to the lines of force in the field; this would place the lower brush in a very awkward position for observation or adjustment. In consequence of this Messrs. Mather and Platt carry the connections from the coils 85° in the rear in the direction of rotation, which brings the points of best collection upon a horizontal line. It is claimed that the armature resistance of this machine is so low, and the magnetic circuit so perfect that with a shunt winding it may be depended upon to regulate its output to the exigencies of the useful portion of the circuit. But if perfect regulation is required it will be found that a few series windings are required, as in other compound dynamos, to compensate for the inevitable fall in the E.M.F. when the maximum current is drawn from the machine.

### Elwell-Parker Dynamo.

At p. 28 is depicted a 5 unit bipolar continuous current machine of this class, of the following dimensions: Length, 4 ft. 4 ins.; width, 1 ft. 10 ins.; height, 2 ft. 4 in.; weight, 12 cwts.; drum armature, and compound wound; speed 1,200 revolutions. It is furnished with fast-and-loose pulley upon the shaft and also with a belt-fork or striking gear for facility in throwing in and out of connection with the motor.

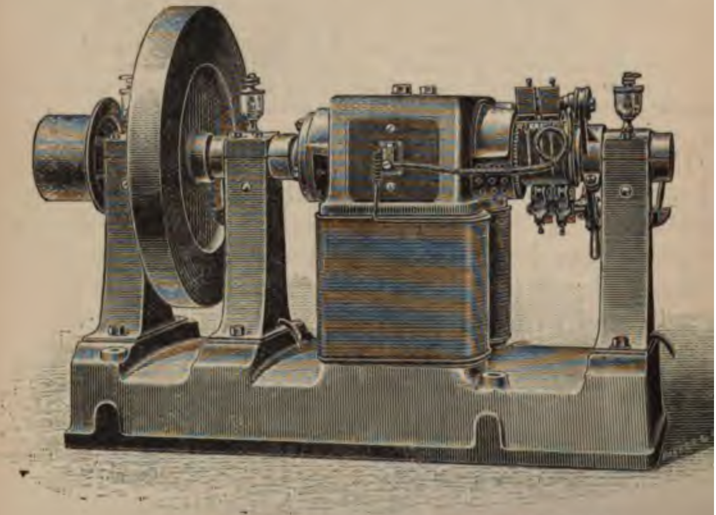

Fig. 85.—Elwell-Parker Dynamo (Overtype, with Fly-wheel).

Fig. 85 represents a 3 unit machine of the same type, but furnished with a balance wheel intended to assist in steadying the fluctuations in speed due to the motor or other cause. These machines are furnished with improved brush brackets, having pressure gear and hold-off catch, and with independent brushes, so that one from each side may be removed and trimmed without disturbing the current.

## Kapp's Dynamos.

The present drift in the direction of the production of dynamos of the "overtype" is due to Mr. Gisbert Kapp, who at an early period of the history of electric lighting recognised the advantages of inverting the field magnet, and by this means obviating "magnetic" leakage (p. 60), and other incidental disadvantages. But the Kapp system has other advantages, as will be seen from the subjoined sectional

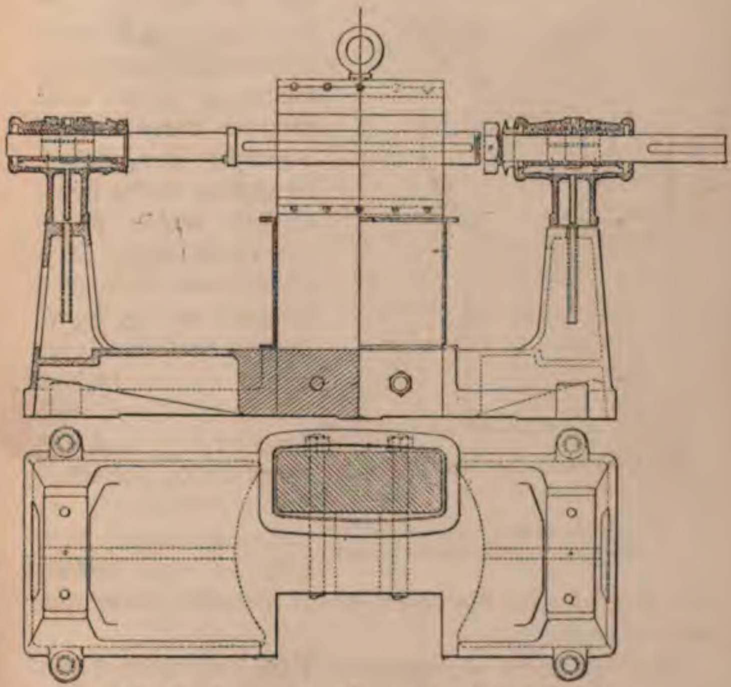

Fig 86.—Kapp's Overtype Dynamo (Longitudinal Section).

views of a two-pole continuous current machine, having an armature 11 by 16 inches.

Fig. 86 is a longitudinal section, and Fig. 87 a transverse section of this machine without the armature. The foundation and bearing standards form one casting. The field magnet cores are of wrought iron, bolted as shown to the foundation, which forms the short yoke. The dimensions of the field magnet are 15 by $5\frac{3}{4}$ inches, section of core = 86 square inches. Shunt windings, each limb 11 layers of 139 turns of ·065 inch wire; series windings, 23 turns of copper tape ·480 by ·130 inches. The fine wire on the two limbs is in series, the copper tape in parallel.

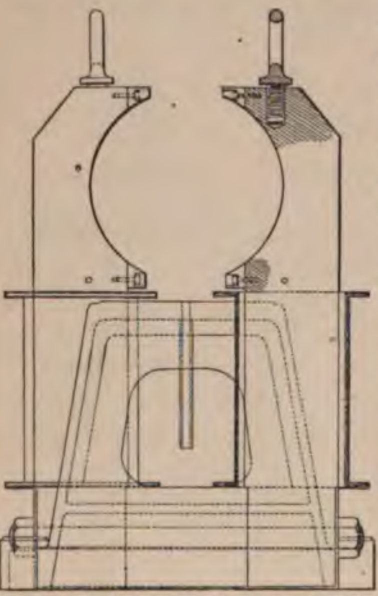

Fig. 87.—Kapp's Dynamo (Transverse Section).

The armature is represented in longitudinal section in Fig. 88. It is built up of soft iron discs, having a radial depth of $2\frac{3}{8}$ inches, and a total diameter of 11 inches, section of the core = 62·5 square inches. Throughout the length of the disc space, there are distributed three pairs of ventilating discs, having driving horns projecting sufficiently to carry the peripheral windings. These arrangements are represented in the ectional view. The windings consist of 120 copper bars, each of ·046 square inches, in sections, resistance = ·014 ohm. These are formed into loops or diametrical pairs by means of arc-plates, 50 mils thick by 1$\frac{5}{8}$ inch deep, called connectors, shown (side view, separated) at the lower side of the figure. These connectors are shown as occupying a space at either end of the armature. They fill the place of the wire crossing the ends of the armature (as Fig. 59, p. 155) wound with wire, but offer much less resistance. The arc plates are insulated in the usual way. Their ends are provided at either extremitywith tags, for connecting, but at right angles to the plane of the segment.

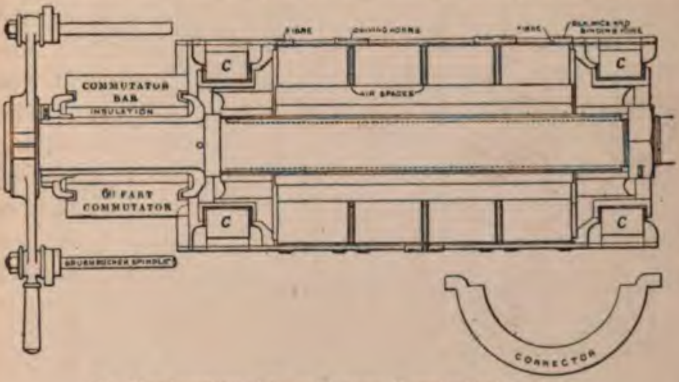

Fig. 88.—Armature of Kapp Dynamo (Longitudinal Section).

The commutator consists of sixty bars, with mica insulation, arranged so that they are bound into cylindrical form by means of the cup-like rings shown, which are in turn fitted to advance upon screws cut upon the shaft.

The brushes are carried upon a rocking frame, provided with levers, capable of motion coaxially with the shaft, as represented.

Output: 21 kilowatts, or 105 volts; 200 ampères; speed 780 revolutions per minute.

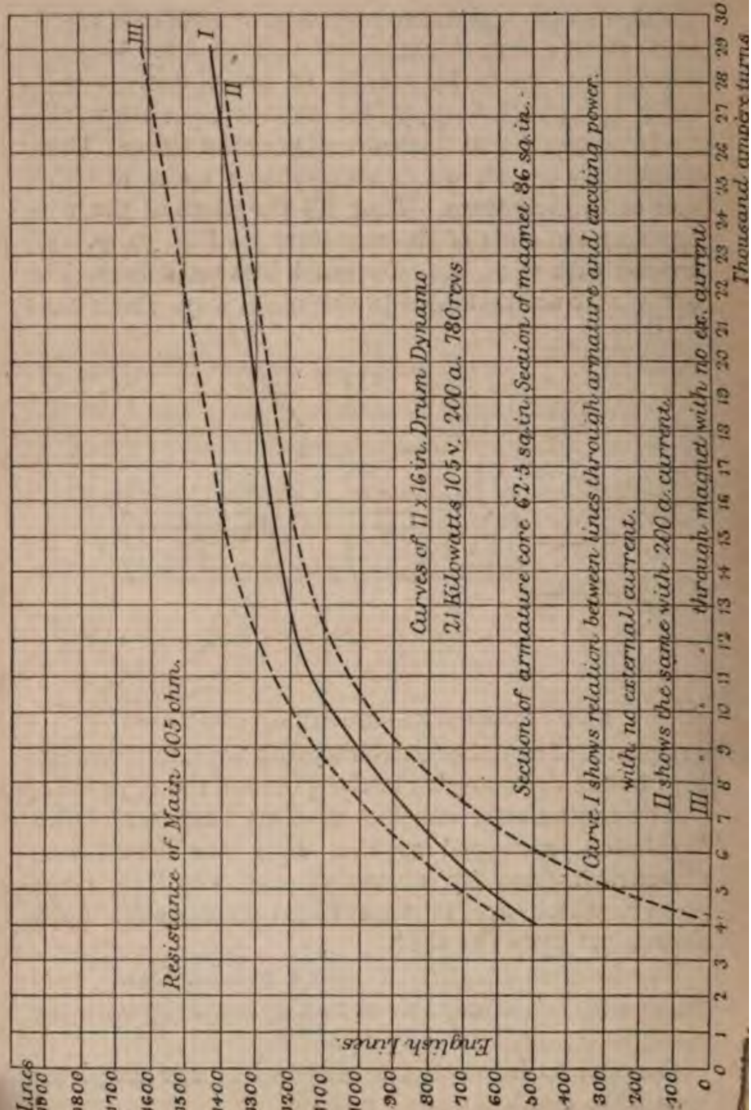
Lines
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
English Lines.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Thousand ampere turns
I
II
III
Resistance of Main ·005 ohm.
Curves of 11 x 16 in. Drum Dynamo
21 Kilowatts 105 v. 200 a. 780 revs
Section of armature core 62·5 sq.in. Section of magnet 36 sq.in.
Curve I shows relation between lines through armature and exciting power
with no external current.
II shows the same with 200 a. current.
III " " through magnet with no ex. current

Fig. 89 shows a series of curves forming a characteristic of the magnetization taken from this dynamo, exhibiting the relationship between the magnet windings and the magnetic lines (English or Kapp lines being represented) in the field. The diagram is self explanatory. A diagram representing the movement of the E.M.F., with different resistances in

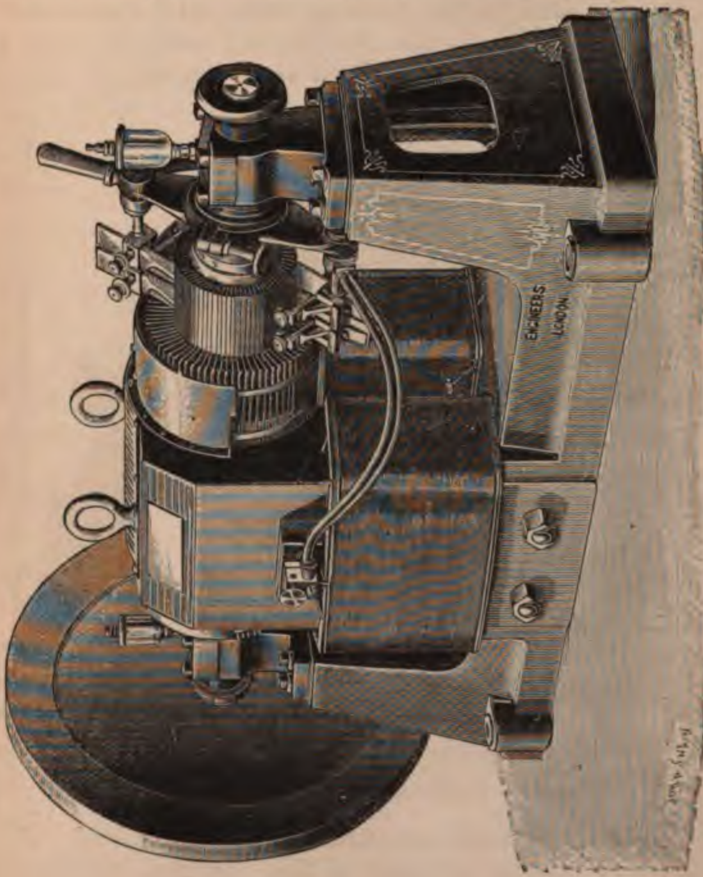

Fig. 90.—Kapp's Overtype Dynamo (General View).

circuit, shows a line so straight that it is not of sufficient interest to warrant representation. Mr. Kapp has in fact been enabled to give to this curve any required form, showing that the proportions subsisting between the two windings, and the character of the magnetic circuit are such that the self regulation is perfect under any condition of load. A general perspective view of this dynamo, engraved from a photograph, is given in Fig. 90. It is furnished with a fly wheel.

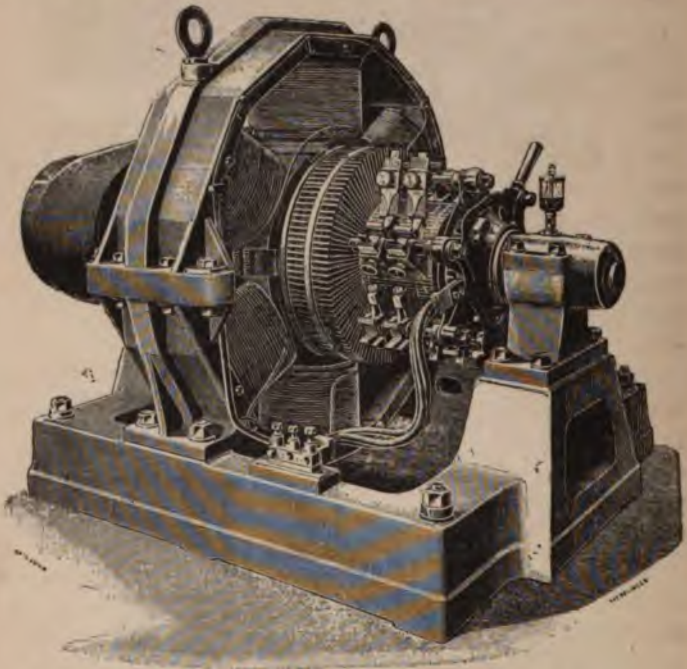
Fig. 91.—Kapp's Central Station Multipolar Dynamo.

*Kapp's Central Station Dynamo.*—The latest class of dynamos for continuous currents introduced by Mr.

Kapp is represented in Fig. 91, which is from a photograph of a large multipolar drum machine, designed for a speed of 450 revolutions per minute, and an output of 1,000 ampères at 50 volts terminal E.M.F. The increase in the number of poles beyond two offers several advantages for large machines which are required to run at a comparatively low speed, among which the most important is the reduction of armature reaction. If an attempt be made to increase the power of machines by simply increasing the linear dimensions of the ordinary bipolar type a limit is soon reached where the magnetic effect of the armature itself begins to become objectionable, not only because it causes a certain reduction in the terminal pressure, but also—and this is the more serious drawback—because it necessitates altering the lead of the brushes if the current varies, and causes liability to sparking at the commutator.

The armature core consists of soft iron discs, is 24 inches external diameter and 12 inches in length. It is provided with driving horns and ventilated in the manner represented in Fig. 86, p. 283, as employed in the bipolar machines, but its large diameter permits of still more efficient internal ventilation.

The field magnet is composed of six cylindrical magnet cores placed radially (inwardly projecting) and joined at their outer ends by a yoke, whilst their inner ends are provided with "pole shoes." The exciting coils, connected as a shunt, are placed upon the radial projections or cores. The field magnet consists entirely of cast iron, and could be made in a single casting, but in order to facilitate insertion of the armature the casting is in two parts divided horizontally, so that the top half may be lifted off, and lighting was carried on for some years, has led to the construction of some very large dynamos now in use at the London Electric Supply Corporation's great station at Deptford. Two of these dynamos are at the present time in daily work. Several others, of a still larger pattern, are in course of construction. Each of the dynamos at present in use was built for an output of electricity sufficient to light 25,000 incandescent lamps; but, we are informed by Mr. Ferranti, "so good a margin has been left, and the machines have proved so efficient, that they will each light 40,000 lamps." The larger dynamos at present being built are intended to each light 200,000 lamps.

*The Ferranti Dynamos at Deptford.*—Before entering upon a detailed description of the large dynamos already constructed, it appears advisable to give some general idea of their appearance, and of the means employed in working them.

The four full-page illustrations that follow are engravings from photographs taken during November, 1890, in the works at Deptford.

Fig. 94 depicts the general appearance of one of the 25,000-light machines in running order. It will be observed that it is driven by ropes, running in grooves in a pulley of great width. The machine itself is disc-like in type. The lubricating arrangements, to which an extraordinary amount of attention has been paid, necessitate the use of a system of tubing, as shown, for the purposes of distributing, collecting, and cleansing the lubricant.

In Fig. 95 is represented the dynamo "racked open" for purposes of examination. The magnet frame may be opened in this way so as to form four distinct parts or half-circles. Mr. Ferranti has devoted great attention to this essential feature in

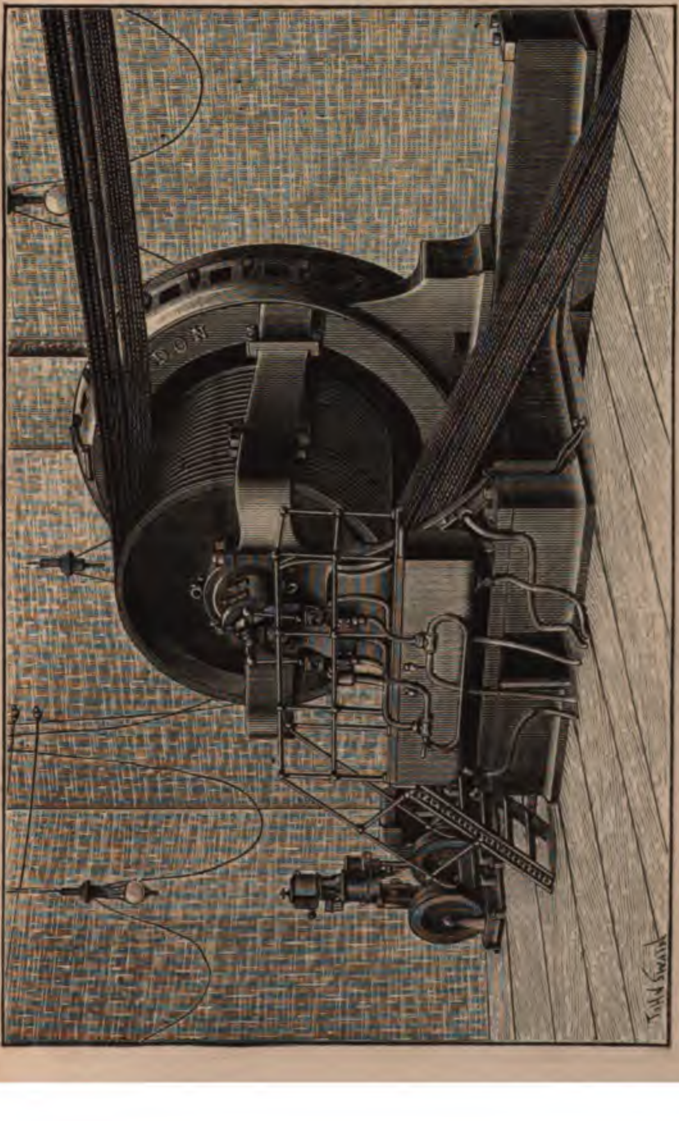

Fig. 94.—Ferranti Alternating-Current Dynamo.

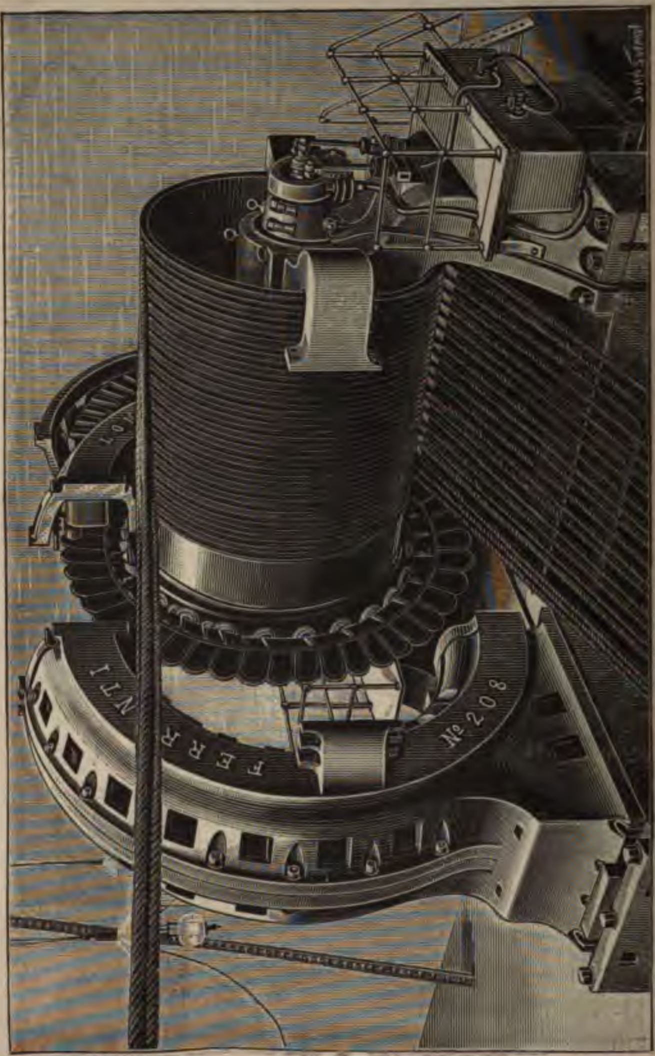

Fig. 95.—Ferranti Dynamo, "open" for Examination.

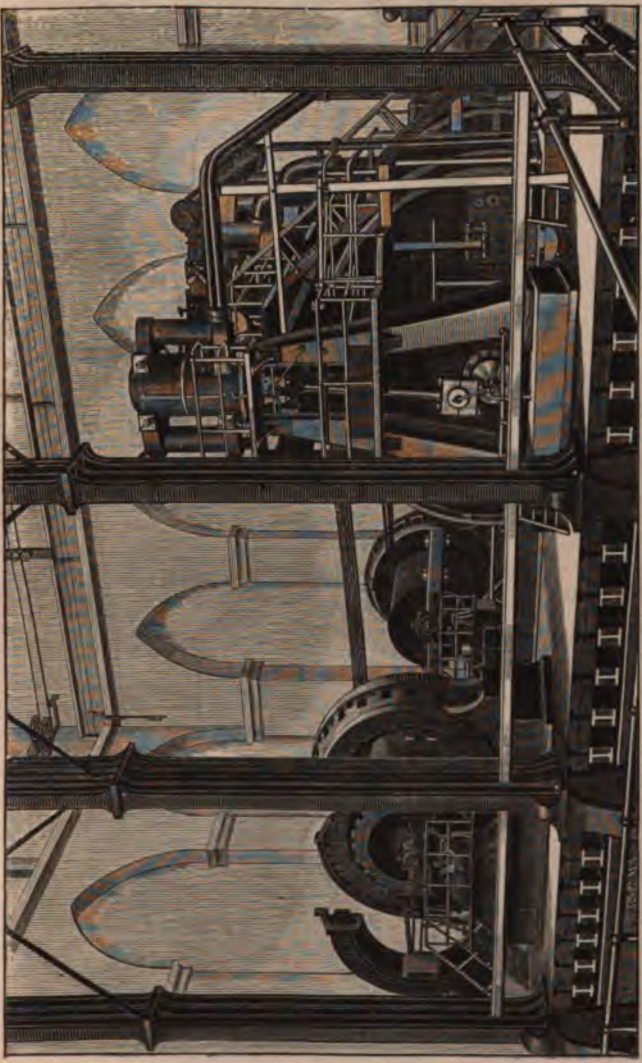

Fig. 96.—Ferranti Dynamos, with their Engines.

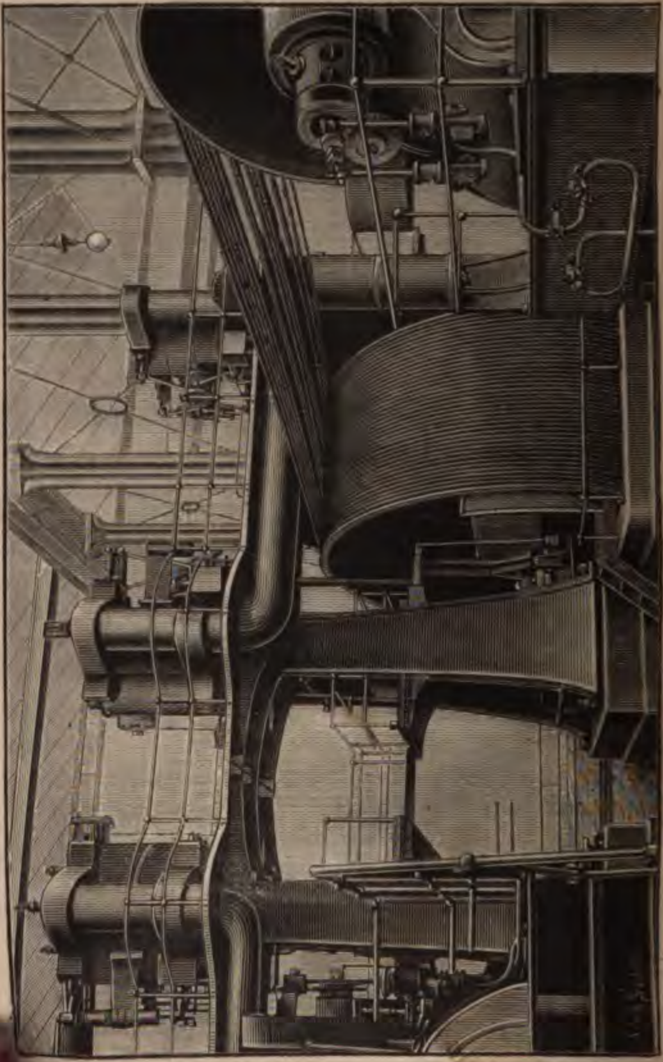

Fig. 97.—Marine Type Driving Engines of Ferranti Dynamos.

large machines. Repairs to, or examination of, the armature and field coils frequently necessitates the taking apart of the greater portion of the dynamo. This involves waste of time, and, in public lighting, when large units of production are employed, this is

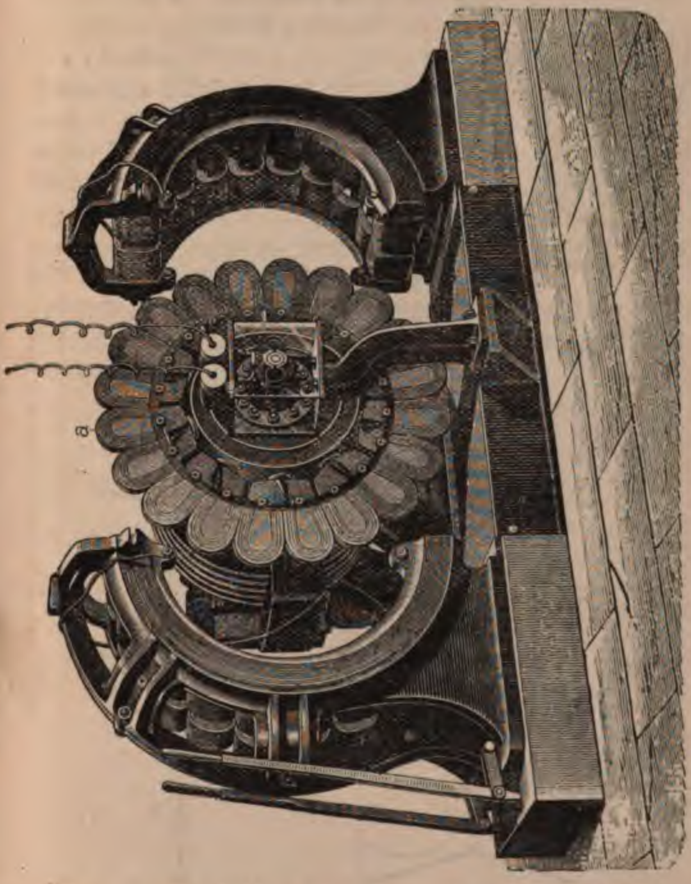

Fig. 98.—Ferranti Dynamo "open," showing Armature and Field Magnets

generally impracticable. The aim of the inventor in this case has been to so arrange the two halves of the field-magnet framing that they might be rapidly separated so as to expose the loops of the armature, and also the field coils themselves. This is effected by furnishing the base of each half with a suitable sliding arrangement, and so separating them in a straight line. It will be readily understood that, since the magnetic field is extremely narrow, and is almost filled by the width

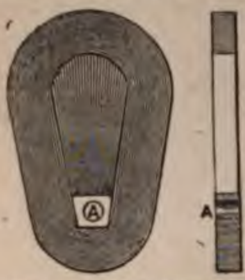

Fig. 99.—Bobbin of Ferranti Armature.

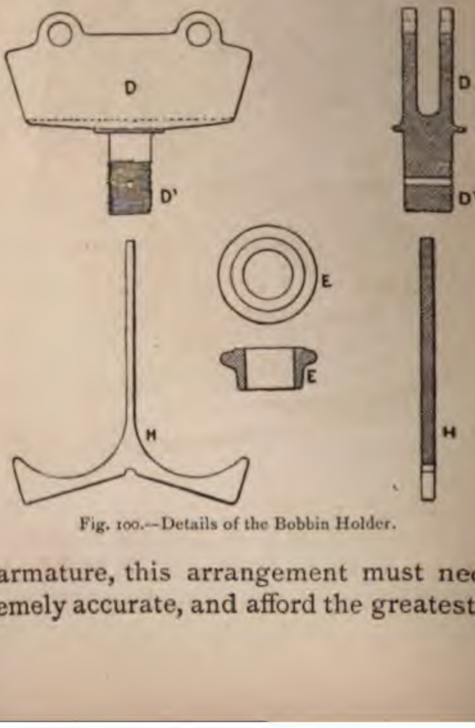

Fig. 100.—Details of the Bobbin Holder.

f the armature, this arrangement must necessarily e extremely accurate, and afford the greatest rigidity to the field magnet frame, when locked in position ready for working.

The pair of dynamos in use at the date of taking these photographs, together with the marine-type driving engines, are depicted in Fig. 96. The nearest of the two machines is shown "open."

In Fig. 97 one of the engines, with a portion of the dynamo connected therewith, and also a part of the companion engine, are represented.

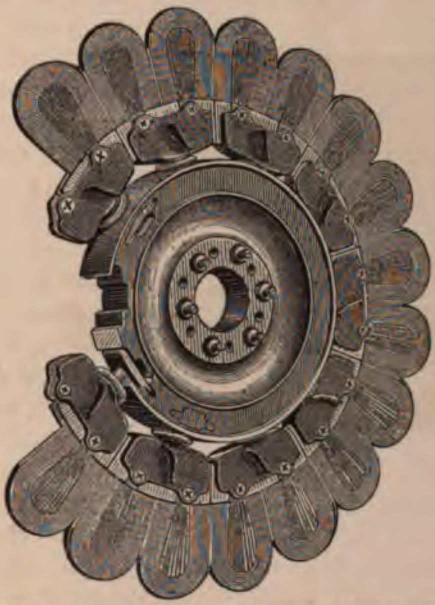

Fig. 101.—Armature Incomplete, showing Method of Mounting the Bobbins.

Some general idea of the dimensions of these great dynamos may be gathered from the size of the armature alone, which has a diameter of about 15 feet. Its normal velocity is 120 revolutions per minute.

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metallic contact rings, revolving with the shaft, furnished with fixed clasps, or rubbing contacts in the form of half circles, L L′, from which the current is led off by $l_2$ to the mains R R.

Fig. 104 is a section taken parallel to the axis of one of the machines now running at Deptford, in

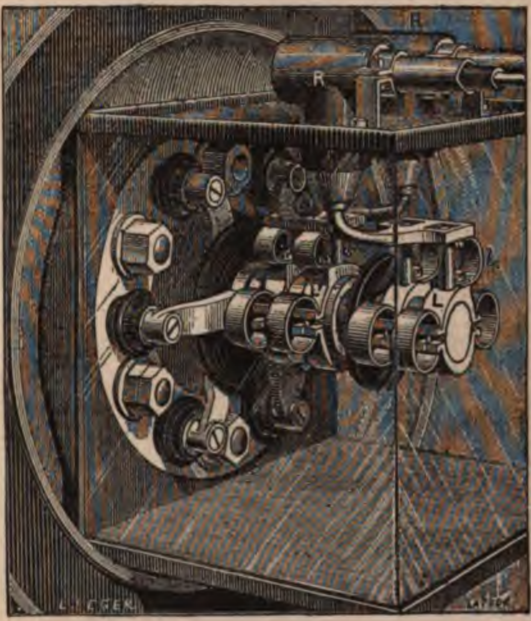

Fig. 103.—View of the Collectors and "Leading off" System.

which the mounting of the armature, E D, is shown in cross section. The field magnets are similarly represented. The great driving drum, N N′, is composed of two sections, bolted together at *a a*. The system of bearings and of lubrication is especially perfect. At R is provided a tank of the lubricant,

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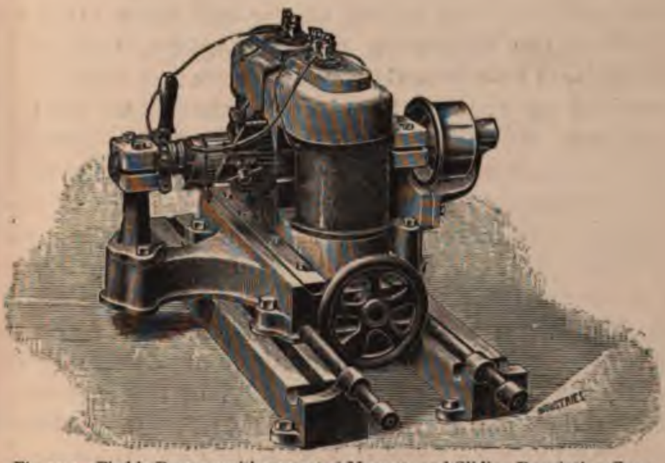

Fig. 105.—Firth's Dynamo with separated Magnets and Sliding Regulating Gear.

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were made with a small series-wound dynamo, with armature 5½ inches diameter by 6 inches long, built for an output of 15 ampères at 100 volts. It will be observed that the proportional fall of the volts exhibits values contrary to general expectation, and the figures altogether strikingly emphasise a growing opinion amongst electrical engineers that the greatest possible *nearness* of pole pieces and armature is not necessarily a corresponding advantage. As in the former case, the measurements were taken between pole faces and the periphery of the armature:—

| Speed. | Distance. | Volts. |
|---|---|---|
| 2,000 | normal | 100 |
| ,, | ⅛ inch | 94 |
| ,, | ¼ ,, | 90 |
| ,, | ⅜ ,, | 86 |
| ,, | ½ ,, | 78 |
| ,, | ⅝ ,, | 76 |
| ,, | ¾ ,, | 68 |
| ,, | ⅞ ,, | 64 |
| ,, | 1 ,, | 56 |
| ,, | 1⅛ inch | 50 |
| ,, | 1¼ ,, | 42 |
| ,, | 1 9/32 inch | 36 |
| ,, | 1 5/16 ,, | 30 |
| ,, | 1 11/32 ,, | 20 |

*Single Coil Field Magnet Dynamo.*—A diagram of this form of dynamo is shown in Fig. 106. It is a type of machine which, while it has been produced by several builders, has received most attention at the hands of Mr. Kennedy. Its chief merit lies in its simplicity. There are only two parts, or at most three, in the field magnet. These are the base or foundation, with which is cast the lower pole piece; the core of the magnet, which is preferably made from wrought iron, but may be of cast iron and produced at once with the foundation; and the cap or upper pole piece. In a machine of this kind built by

Mr. Kennedy, the core of the magnet is of hammere scrap iron and measures 10 inches in diameter and 1 inches in length. The pole pieces are of hemati iron. The armature is of the Gramme type and built of charcoal-iron discs turned true outside ar inside. It is mounted on a spoked wheel keyed t the shaft. The core is 12 inches in length, the rin

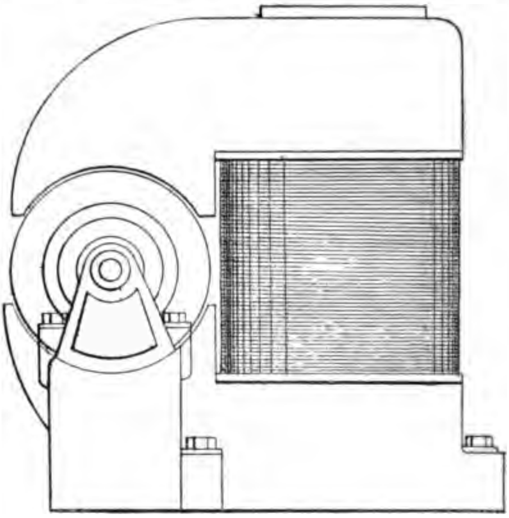

Fig. 106.—Diagram of Kennedy's Single Bobbin Dynamo.

being of the cylinder type. Its external diameter 10 inches, and its internal diameter 6 inches. It wound with flat wire 5 mm. by 3·7 mm. in one lay outside. The current allowed in the armature is ampères. The commutator is composed of solid draw copper sections insulated with mica. Resistance armature, ·04 ohm; resistance of shunt coil, 20 ohm resistance of series turns, ·03 ohm; speed, 620 revol tions; E.M.F. at terminals, open circuit 100 volts.

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and this is caused to revolve in the cup-like recesses of a similar field magnet. The armature winding is, however, different, consisting as it does of numerous coils connected to a commutator of a large number of sections. The output of this dynamo has the features of the low tension direct system, a low

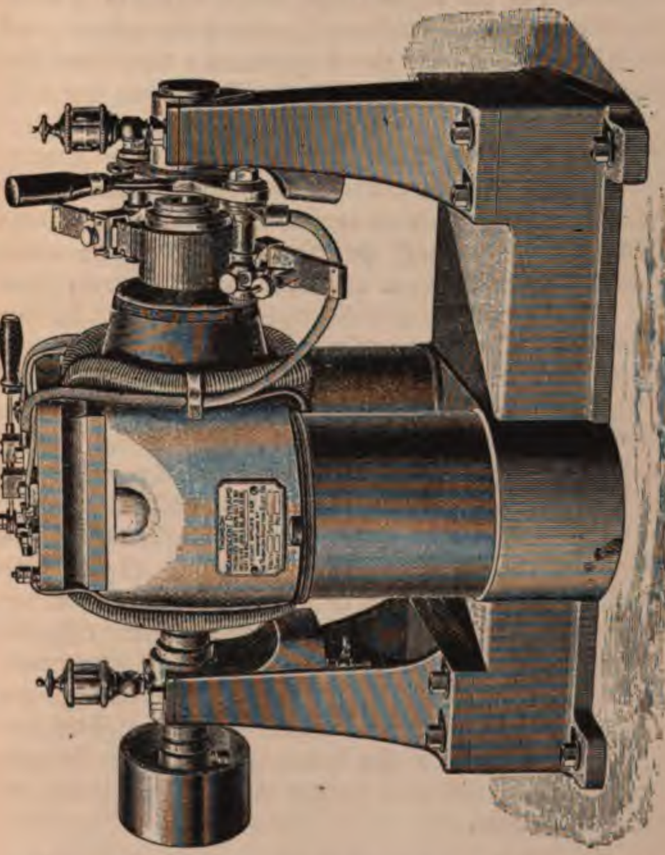

Fig. 108.—Thomson-Houston Overtype Bipolar Dynamo.

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*Thomson-Houston "Motor-type" Dynamo.*—As will be observed by reference to Fig. 108, which gives a general view of the machine, this dynamo belongs to the class known in England as the "bipolar overtype." It is built chiefly for the lighting of isolated installations, but as this work is largely done by the class previously described, the "motor-type" has been chiefly utilised as exciters for alternating current dynamos and as motors or generators for the transmission of power. The armature is of the usual drum type, and is wound for a low tension output and large current. The chief peculiarity, however, consists in the dispositions of the series windings, when the dynamo is compound wound. These are arranged, as represented in the figure, at either extremity of the armature and close to the edges of the pole pieces. The other details of the dynamo are of the usual kind, the brush rocker being of excellent design. This class is built in several sizes, but the following data of five of them will serve to show the relationship between weight, output, speed, power as a motor and so forth:—

| Class. | No. of 60 watt Lamps. Volts. |  | H.P. as a Motor. | Weight, lbs. | Revs. per Minute. | Floor space, ins. | Diam. of Pulley, ins. |
|---|---|---|---|---|---|---|---|
|  | 125 | 80 |  |  |  |  |  |
| 1 | 35 | 45 | 3 | 480 | 2,000 | 29 × 16 | 5 |
| 3 | 100 | 125 | 7½ | 1,080 | 1,600 | 37 × 21 | 8 |
| 6 | 200 | 250 | 15 | 1,943 | 1,400 | 44 × 27 | 10 |
| 20 | 600 | 800 | 60 | — | 1,020 | 81 × 40 | 17 |
| 25 | 800 | 1050 | 75 | 10,000 | 900 | 88 × 46 | 19 |

*Alternating Current Thomson-Houston Dynamo.*—For electric lighting on the incandescent system, at distances over 6,000 feet radius, the use of alternating currents of high tension is becoming common. In Fig. 109 is depicted the leading features of the alternator, built for the system under consideration. The main framework is of cast iron. The field magnet circle is built in two halves. The lower half is cast as

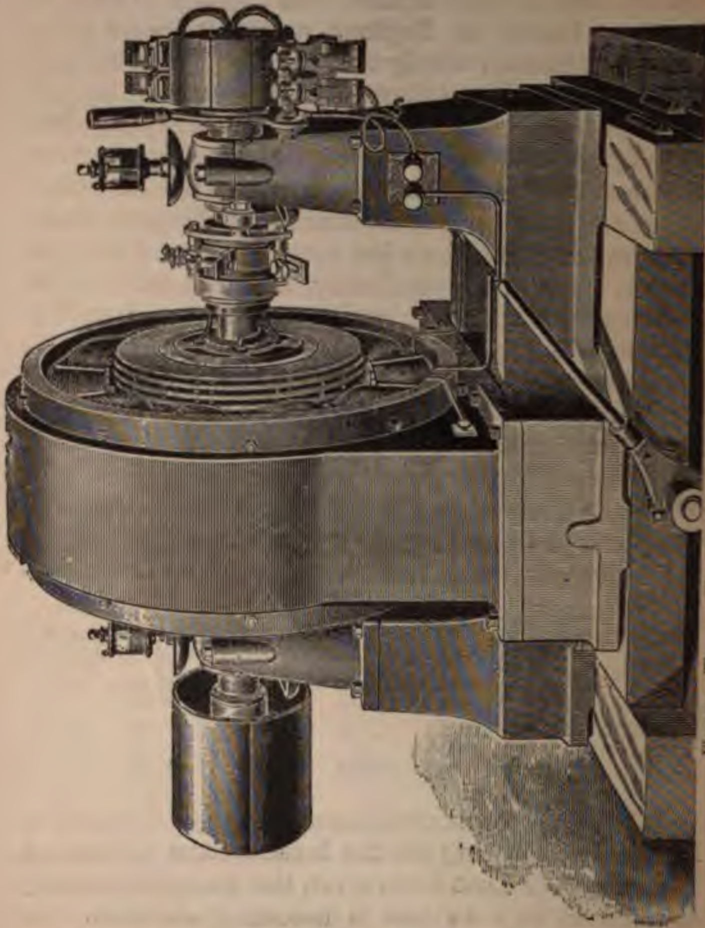

Fig. 109.—Thomson-Houston Alternating Current Self-Exciting Dynamo.

one with the base. The upper half is bolted to it. By these means it is a simple matter to separate them, and to lift out the armature. Each half circle carries, projecting radially inwards, a series of magnet poles, forming the half of the whole number alternately N and S. The number of these in the smallest machine is eight. In the large machines there are as many as twenty-two. The armature is composed of a drum core of iron discs, pierced for ventilation, separated by insulating substance, and bound together in the usual way to form a solid body in the cylindrical form. The coils are in the form of flat hanks. They are laid upon the surface of the drum, and secured in position. The wire used in forming the hanks is of square cross section. There are an equal number of coils on the armature and poles forming the magnetic field. When the dynamo is intended to be self-exciting, as in the particular machine represented by the engraving, these coils are formed with a central open space. This space is then filled with the coils whose function it is to generate current for exciting the field magnets. The whole is bound with brass wire bands. In the smaller machines the lighting coils are connected up in one series with the external work. In the larger dynamos there are two series, connected in parallel. There are several different methods of exciting the field. The simplest is the employment of a separate exciting dynamo of small size. This is generally of the overtype already described. Again, the dynamo may be entirely self-excited as in the case under review. Further, it may be "*composite wound.*"

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central station dynamo, which is in appearance very similar to Fig. 109, p. 314, the armature is composed of iron discs, pierced for ventilation, and having recessed projections, forming "heads," as represented in the cross-section, Fig. 110. It will be observed, in respect to this peculiarity, that the coils are wound in those neck-like recesses, the heads projecting over the coils, in the manner of the top of a mushroom-headed

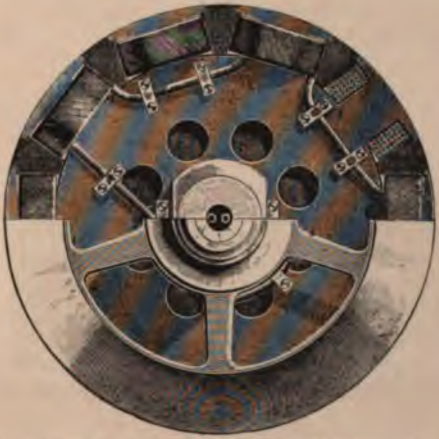

Fig. 110.—Westinghouse Alternating Current Armature. End View. One coil in cross section.

screw, as shown in the coil to the right, shown in cross section. The spaces between the coils and the heads are filled with wooden sections, shown darker. When the iron discs are built together to form the core the recessed portions form longitudinal channels, partially shrouded by the heads. The coils are not actually wound in these recesses. One of the coils is shown in Fig. 111. It is wound by machine. When slipped into position parallel to the axis of the

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ends of the coils, and gives the armature a compact appearance. The terminal wires are carried away to the collecting rings through a canal bored lengthwise of the shaft, as represented. This armature presents the decided advantage that the coils are independent of each other; that they can be quickly removed and replaced if damaged, and that they are so protected by the covers of the channels and the wooden packing pieces that they are not liable to injury mechanically. Provided the insulation be good no harm can come to coils so disposed, unless by the generation of an abnormally large current, which might, as in other armatures, destroy them by heat.

The field magnets which present no peculiar feature form a series of radial pole pieces, of oblong section, with rounded ends, of alternate polarity. The cores are cast solid with the base and cap respectively. These two halves can be readily separated, and the armature lifted out of the frame. The coils are wound upon metal shells, which are readily slipped over the cores, and this feature presents the advantage that burnt or damaged coils can be quickly replaced. The field may be excited by a separate dynamo, as is generally the case; but it may obviously be fed by a portion of the alternating current being commuted and shunted into it. In the central station dynamo the number of poles in the field is sixteen, their coils being joined up in two series of eight, and the two series in parallel. It is excited by a continuous current of from 25 to 30 ampères, under a pressure of 100 volts. The armature coils are similarly connected. The usual speed is 1,000 revolutions per minute. The number of complete periods in the alternations are, at this speed, 130 per second, or 8,000 per minute. The usual working pressure is 1,000 volts. This current is obviously intended for transmission to distances, and works through step-down connectors, by means of which it is reduced to 100 or 50 volts, as the case may require.

*Westinghouse Safety Device.* — One of the most interesting features of the Westinghouse system is the device for obviating a possible abnormal and destructive current in the armature of the dynamo.

In a continuous current machine a break in the line generally causes a cessation of the current in the armature, when the dynamo is wound in series. But in the system under examination a break in the external portion of the circuit causes the generation of an abnormally heavy current in the armature, which, if not checked, would eventually cause its destruction by burning. To prevent this a short circuiting apparatus is attached to each dynamo of this type. It consists of a single soft-iron core enveloped by a solinoid or coil of wire. Near to this solinoid two metallic points occur, connected respectively to the positive and negative terminals of the dynamo, circuited through the solinoid. When an abnormal electromotive force occurs in the armature it is sufficient to cause sparks to leap across from point to point. This causes a sufficient current to pass at the breach to energise the solinoid. Its core becomes magnetic. An armature is attracted by it, and this armature is made to break the armature's circuit, so cutting it out or, more correctly, short circuiting it. A short circuiting of the armature is followed by a powerful counter induction in its coils, sufficient to dam back the heavy current, and reduce it to, or under, the normal strength, so that no destructive heating of the coils can take place.

Normally the distance between the points spoken of above is so adjusted that any excess of current above twelve ampères causes the arc to be established, and so effecting the required short circuiting.

In addition to the protective nature of the above apparatus still another means is provided within the machine to obviate a possible abnormal current in the armature coils. This consists simply of a pair of points, connected respectively to each of the two collector rings upon the shaft. Upon the current exceeding a certain predetermined value there occurs a spark between these two points, causing a direct short circuiting of the armature, the inductive effect of which then reduces the current to the normal value.

*Westinghouse's Cut-out.*—In connection with the dynamo, and placed where required upon the line or external circuit, a cut-out or safety fuse is employed, the nature of which calls for a short description. It consists of a double safety cut-out. It is composed of the usual strips of fusible alloy, or of tin band; but in addition to the points across which they span they are shunted by means of a highly resisting German silver wire. It frequently happens that upon the fusing of a cut-out an arc forms at the imperfect break, which, experience shows, is apt to travel backwards and burn the contacts, and thus destroy the entire device before the arc is broken. By the employment of a high resistance shunt around those points the fusing of the metal strip diverts a current through the shunt wire, which at once fuses, breaking into small pieces, and forming directly a break of six

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On the other hand, a reduction of resistance in the working portion of the circuit causes a lag in the current phase, so that the maximum point is attained at an instant in time more nearly coincident with the opposition of similar poles. And when the armature coils are short circuited, and the lag reaches its maximum, the magnetization of the armature pole occurs approximately at the time of its transit under a field pole of opposing polarity. Since the windings of the field magnets and armature are such as to set up approximately equal magnetic potentials in opposite directions, the cutting of lines of force is now reduced to a minimum value sufficient to cause the flow of a normal current through the coils.

It is said that the current characteristic of this machine can be made to approach as nearly to consistency as can the electromotive force characteristic of any constant potential dynamo under conditions of varying current. As these alternators are used extensively in the lighting of arc lamps capable of being fed by alternating currents, this attribute of the armature is of especial value.

Under conditions of light load the efficiency of the Westinghouse alternator is, similarly to that of other alternators, rather low, but beginning with 40 lamps up to the full capacity of the machine the efficiency rises rapidly, until at full load it approximates 87 per cent., and the energy per lamp required is but ·75 horse power. The following tests of the machine were made at the Westinghouse Company's works at Pittsburg. The engine used was of the Westinghouse single acting two cylinder type, the diameter of the cylinders being 14½ inches, and the length of stroke 30 inches :—

TABLE OF TESTS MADE WITH AN ALTERNATING-CURRENT (WESTINGHOUSE) DYNAMO.

| Load. | Average Pressure per sq. in. Right Cylinder. | Average Pressure per sq. in. Left Cylinder. | Average Pressure both Cylinders. | Average Speed. Revolutions. | H.P. Indicated. | H.P. Neglecting Engine and Shaft. | Ampères in Lamp Line. | H.P. per Lamp. | Apparent Watts in Lamp Line. | Apparent H.P. in Lamp Line and Apparent Efficiency. |
|---|---|---|---|---|---|---|---|---|---|---|
| | lbs. | lbs. | lbs. | | | | | | | H.P. |
| Engine and Shaft . | 6·85 | 6·03 | 6·44 | 301·3 | 21·04 | | | | | |
| Dynamo and Exciter . | 6·72 | 7·53 | 7·12 | 302·4 | 23·40 | 2·36 | | | | |
| Dynamo, Short-circuited | 8·67 | 10·62 | 9·64 | 298·4 | 30·90 | 9·86 | | | | |
| Dynamo, Short-circuited through Converters . | 11·45 | 13·49 | 12·47 | 300·0 | 40·56 | 19·52 | | | | |
| Dynamo, Converters and 10 lamps . . . | 13·25 | 14·57 | 13·91 | 297·8 | 44·9 | 23·85 | 10 | 2·38 | 4,660 | 6·2, 26 % |
| Dynamo, Converters and 40 lamps . . . | 18·12 | 20·3 | 19·21 | 291·0 | 60·6 | 39·56 | 10 | 0·989 | 18,800 | 25·2, 63·7 % |
| Dynamo, Converters and 80 lamps . . . | 25·9 | 28·4 | 27·15 | 288·8 | 85·1 | 64·06 | 10 | 0·801 | 37,860 | 50·7, 79 % |
| Dynamo, Converters and 100 lamps . . . | 31·32 | 33·13 | 32·22 | 290·5 | 101·5 | 80·46 | 10 | 0·805 | 49,150 | 65·9, 82 % |
| Dynamo, Converters and 120 lamps . . . | 35·2 | 36·9 | 36·05 | 285·4 | 111·5 | 90·46 | 10 | 0·754 | 58,980 | 79·06, 87 % |

While the continuous direction current dynamo has received a good deal of attention in order to afford means of investigating the causes of its performance under varying conditions, and the determination of its efficiency, very little has been done in this way in the case of the alternating-current machine. Some experiments have lately, however, been carried out at the Franklin Institute by Dr. Duncan and Mr. Hasson upon a Westinghouse alternator, working in conjunction with converters of the same system.

The apparatus consisted of a Westinghouse 750-light No. 1 dynamo, excited by a small continuous current machine, and an outfit of 40-light converters. The driving plant consisted of a 75-h.p. Armington and Sims engine, driving the dynamo and exciter through a Tatham transmission dynamometer. Engine, dynamometer, and dynamos were firmly secured to heavy parallel timbers, which served as a foundation. The converters were banked on a wooden framework at a distance of some thirty yards from the dynamo, and their primaries were permanently secured to the dynamo circuit, a switch in the latter serving to cut them off when desired. The ammeter belonging to the plant was put in this circuit, and was read when efficiency measurements were being taken. The secondaries of the converters were conveyed to a switch board, and then to incandescent lamps mounted on racks. The first experiments had reference to

*Power Measurements.*—The Armington and Sims engine supplying the power worked regularly and satisfactorily, and the governor could be adjusted to give the speed required at the dynamo. The Tatham dynamometer was the one used for power measurements at the Electrical Exhibition held at Philadelphia in 1884, when its accuracy was checked by making with it a determination of the mechanical equivalent of heat. The result obtained in the latter measurement was 772·8 foot pounds per degree Fahr., and shows that the dynamometer is practically accurate. Since this form of dynamometer is likely to be largely used in future tests of power electrical apparatus, it may prove useful to briefly describe its construction by the aid of a diagram.

In Fig. 113 is shown an endless belt, passing over the driven pulley S to the shaft to which the engine is belted, round the pulleys S and B to the driving pulley A, and back over $B_1$ and $S_1$ to S again. The bearings of the pulleys B and $B_1$ are in cradles pivoted on knife edges, C, at their outer ends, and at the inner ends are connected by links at equal distances on the two sides of a knife edge which supports the scale beam W. The outer side of the belt passes through the line of the knife edges, C, and therefore has no effect on the scale beam, but the tensions of the inner parts of the belt act directly on the scale beam, and as they are on opposite sides of the fulcrum, they act against one another. The beam is so graduated that this difference of tension is read off directly in pounds, and this quantity—the difference of tension of the belt on the two sides of A—

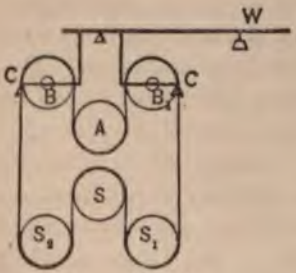

Fig. 113.

multiplied by its circumference and speed—gives the horse-power delivered. A weight travels on the beam, W, and readings can be taken with great accuracy.

*Electrical Measurements.*—The energy in the secondary circuit was measured by means of a Cardew voltmeter and a Thomson ampère balance. As it is not the custom to put a number of secondaries in parallel each converter had its separate lamp circuit. Before making an efficiency test the electromotive force in the primary was regulated—there being a Cardew voltmeter in that circuit—and a separate measurement of the electromotive force and current in each secondary circuit was made. When the test was actually in progress the voltmeter and ampère balance were used in one of the circuits, and the currents and electromotive forces in the others were calculated from the readings in this circuit, together with the previous measurements. Both the voltmeter and ampère balance were accurately calibrated, the former being checked after each test, while the latter had its constant determined with both continuous and alternating currents. The electromotive force at the terminals of a non-inductive German silver resistance in circuit in the balance was observed when a continuous current was flowing, and also with an alternating current of the same periodicity as that employed in the test. The current in each case was calculated from the resistance and electromotive force, and the results gave no appreciable difference in the constant for continuous and alternating circuits. The tests were carried out as in the following tables:—

HORSE-POWER ABSORBED AND VARYING ELECTROMOTIVE FORCES.

| | E.M.F. | | H.P. |
|---|---|---|---|
| | Dynamo. | Exciter. | |
| Horse-Power for Exciter, Field not made | 0 | 0 | ·34 |
| " " " " Field made . | 0 | 110 | ·75 |
| " " " Dynamo alone . . | 0 | 0 | 2·73 |
| " " " Dynamo and Exciter . | 0 | 0 | 3·04 |
| " " " " " " . | 0 | 107 | 3·51 |
| " " " " " " . | 1376 | 124 | 12·5 |
| " " " " " " . | 1168 | 104 | 10·1 |
| " " " " " " . | 1099 | 105 | 9·60 |
| " " " " " " . | 1040 | 105 | 9·0 |
| " " Primaries of Converters on . | 1216 | 105 | 12·0 |
| " " " " . | 1171 | 104 | 11·8 |
| " " " " . | 1107 | 104 | 11·12 |
| " " " " . | 1048 | 104 | 10·64 |

TABLE OF EFFICIENCY AT VARYING LOADS.

| Approximate Load. | EXCITER. | | DYNAMO PRIMARY. | | CONVERTERS. | | Horse-Power in Lamp Circuit. | Mechanical Horse-Power. | Loss in Horse-Power. | Efficiency per cent. |
|---|---|---|---|---|---|---|---|---|---|---|
| | E.M.F. | Current. | E.M.F. | Current. | E.M.F. | Current. | | | | |
| ¼ | 105 | 9·4 | 1,107 | 10 | 49·5 | 153·9 | 10·21 | 21·83 | 11·62 | 46·8 |
| ½ | 104 | 10·5 | 1,107 | 18·9 | 49·6 | 338·4 | 22·50 | 34·4 | 11·90 | 65·4 |
| ¾ | 101 | 11·0 | 1,113 | 28·6 | 50·0 | 520·7 | 34·9 | 48·0 | 13·1 | 72·7 |
| Full | 112 | 11·5 | 1,123 | 38·1 | 50·9 | 739·8 | 50·48 | 64·44 | 13·96 | 78·3 |

In connection with this subject it may be instructive to give the results of the experiments made with the converters worked in conjunction with the dynamo.

## EFFICIENCY OF CONVERTERS.

### FORTY-LIGHT CONVERTER.

| No. of Lamps. | Volts. | Watts in Secondary. | Loss in Watts. | Loss in Iron. | Efficiency. |
|---|---|---|---|---|---|
| 40 | 50·0 | 2,001 | 109 | .. | 94·8 |
| 0 | 50·9 | 0 | 84 | 84 | .. |

TWENTY-LIGHT CONVERTER.

| No. of Lamps. | Volts. | Watts in Secondary. | Loss in Watts in Secondary. | Loss in Iron, Watts. | Efficiency per cent. |
|---|---|---|---|---|---|
| 20 | 48·8 | 952 | 106 | 95·2 | 90·0 |
| 15 | 52·2 | 817 | 114·8 | 108·9 | 87·6 |
| 10 | 50·3 | 506 | 101·7 | 99·2 | 83·3 |
| 5 | 51·44 | 264 | 109·4 | 108·7 | 70·7 |
| 0 | 52·3 | 0 | 110·5 | 110·5 | 0 |

The efficiency of the converters was measured by placing them in a metal calorimeter, between the double walls of which water was allowed to flow. The temperature of exit and entrance was observed, as well as the weight of water which passed through; at the same time the current and electromotive force in the secondary circuit of the converter were measured. A separate observation gave the radiation, which was of course allowed for, although it was made as small as possible.

Examining these figures, we are struck by two things: the very large amount of power absorbed in the core of the armature and the very small loss in the converters on open circuit. The dynamo losses due to reversals of magnetism and eddy currents at the electromotive force used in the test are no less than 6 horse power, while the energy due to reversal of magnetism and eddy currents in the converters is only 1·6 horse power. Another rather striking thing is the almost constant ratio of primary and secondary currents over a considerable range. The maximum efficiency is about 78 per cent.

## CHAPTER XXI.

### *THE DYNAMO AS A MOTOR.*

IF the terminals of a dynamo in motion be connected with the terminals of a dynamo standing idle, the current from the active dynamo will traverse the circuit of the idle machine and cause its armature to revolve. The first machine acts as a generator; the second machine becomes a motor. The conductors employed to convey the current from the generator to the motor exemplify the principle of the electrical transference of energy. Since the efficiency of such a system is very high, the transmission and distribution of motive power by means of electricity is being rapidly utilised for various purposes, among which the Electrical Railway is likely to occupy the first place.

### Magnetic Principles of the Motor.

If a straight wire be placed in a magnetic field with its length perpendicular to the lines of magnetic force, and a current passed through it, it will experience a force tending to move it perpendicularly to itself and to the lines of the field. Provided the wire be free to act under the influence of this moving force, it will tend to cut the magnetic field, and a counter, or opposite, current is induced in it. Hence, while the wire (or armature) is impelled to move across the magnetic lines, it acts to a certain extent also as a generator. The counter electromotive force induced in it greatly diminishes, or dams back, the moving current. The more rapid the motion of the armature the greater does this counter current become. Its strength is also dependent upon the strength of the magnetic field.

This magnetic reaction of the armature of a motor is a matter of the greatest importance in the electrical transference of power. The current in the coils of an iron-cored generator armature tends to make that core become a magnet, having poles opposed to those creating the magnetic field. This is well known as the reaction of the armature. In cases where the field magnet is weak it becomes a serious source of loss and other drawbacks. In dynamos, however, it is the builder's aim to set up so powerful a field relatively to the possible counter action of the armature core that the latter is entirely overpowered.

Let us now consider the case of a dynamo becoming a motor.

Let a current be passed into it so that the polarity of the field is the same as when the machine acts as a dynamo. It will be found that the current in the armature is in a direction the reverse of that induced in it as a generator. The polarity of the armature will also be reversed—that is, it will exhibit poles the reverse of those of the field. These poles will mutually *attract* or *strengthen* one another. Hence, the reaction of the armature's magnetism in a motor is contrary to what it is as a generator. But as in the case of a generator this is not an advantage, but on the whole the reverse, and it is the aim of the motor builder to employ so powerful a field magnet that the armature's magnetic reaction may be left almost out of account. As in the case of a generator the reaction tends to distort the direction of the lines of force in the field, and this distortion is the main cause of the necessity for "lead" in the brushes as employed in the case of generators.

Hence, it is important to remember, that, in a perfect motor the twist (torque) communicated to the armature shaft is due not to the magnetism of the iron-core but to the currents in the coils enveloping it. Mechanically considered, therefore, the means of attaching the latter through the core to the shaft demands considerable attention, otherwise the coils are apt to be pulled backwards from their proper position upon the core. Such faults were of constant occurrence in both the earlier dynamos and motors.

## Efficiency of Electrical Transmission.

The electrical transference of motive power has been found to be more efficient than transmission by ropes, water, or compressed air. This fact alone has sufficed to bring electro-motors into use, in many cases to the displacement of every other workable system.

The whole of the power supplied electrically to the motor is not, however, converted into mechanical effect. There are various unavoidable sources of loss. There is, first, the resistance of the connecting wires. This may be regarded as the loss due to transmission. There is, in the second place, a certain loss due to resistance, which appears as heat in the motor. Thirdly, there is the loss due to friction, mechanically considered, of the motor. There is, also, the invariable magnetic friction giving rise to eddy currents in the motor, but this is frequently so small in the best types that it may be left out of account.

The electrical power put into the motor is most conveniently expressed in watts. If C be the current, expressed in ampères, which actually flows in the circuit of the motor, and E be the electromotive force, expressed in volts, at the terminals of the motor, then the electrical power (per second) in watts, P, is found by multiplying together the ampères and volts, and dividing by 746 to obtain the electrical horse power.

$$\text{Electrical Horse Power} = \frac{E\,C}{746}.$$

Since only a proportion of the electrical power supplied to the motor (owing to causes already mentioned), is returned as mechanical effect at its pulley, it is convenient to express the efficiency of the motor as follows. If C is the current (in ampères) that flows through the motor, and E the electromotive force (in volts) the watts, P, of mechanical effect is

$$P = E\,C.$$

The counter electromotive force of the armature varies with different motors. In the best types it is from five to ten per cent. less than the E.M F. measured at the terminals of the motor.

## Conditions of Electrical Transmission of Power.

The simplest case is that in which a dynamo at one place is connected in circuit with a dynamo (motor) at another place. The conductors between the machines must be insulated in the usual way. That is, if they are of naked copper they must be suspended above the ground and attached to insulators. If they are of the nature of heavily protected cable, they may either be laid along the ground or buried beneath it. In many cases they are laid in water, as across streams. In the case of simply running a dynamo and a motor in this way the machines should be adapted to the work to be done. In most cases the generating dynamo is moved at a constant speed. In that case both the generator and the motor should be series-wound machines. When the generator is run at a constant speed the motor will also maintain an approximately constant speed under all conditions of load. The speed in this case depends entirely upon the E.M.F. The torque depends, on the other hand, entirely upon the current. This is known as simple series transmission.

But in the case of motors being run off circuits used also for lighting, where, instead of constant current constant potential is required, as on an incandescent light circuit, series motors are found to be unsuitable; they will not maintain a constant speed under varying loads. But any shunt wound or compounded motor will do this under the above conditions, because the current through the shunt does not vary, and there is less variation of the strength of the field. Shunt-wound motors, if they are to maintain a constant speed upon a constant potential circuit must be furnished with armatures of low resistance. The field magnet must be relatively very powerful. If a shunt motor, on the other hand, be put upon a constant current circuit (such as that running arc lamps) its speed will increase with its load, and will always fall off as the load is diminished.

*Generators as Motors.*—There is this distinction to be remembered in the cases of setting dynamos to work as motors, or motors as dynamos. Taking the case of an ordinary series machine with brushes set (and having forward "lead") it will, when worked as a motor, run in the wrong direction, or against its brushes. It is usual in this case to reverse the direction of the current in the field magnet, by changing the connections, or, leaving the field magnet, to reverse the connections of the armature. The machine will then run with its brushes. If these connections be left standing the brushes must be reversed and set with the lead in the other direction.

*Shunt Dynamo as Motor.*—Shunt dynamos, however, are not subject to the same rule, for it is evident that while the current in the armature is in the same direction as before, that in the shunt will necessarily be in the reverse direction, and the machine will run as a motor without further change.

*Compound Dynamo as Motor.*—The case of a compound machine is somewhat different. It depends upon the relative magnetising effects of the shunt and series coils whether it will behave as a series or as a shunt dynamo in the direction of its motion. If the shunt, as is usually the case, have a greater magnetising effect than the series turns, the machine will act as a shunt dynamo, inasmuch as it will run as a motor in the same direction as it does as a generator. If, however, as is sometimes the case, the series coils preponderate in determining the magnetic polarity of the field, the machine will run against its brushes, and it must be reversed by altering the connections, as in the case of a series motor. Since the compound dynamo has the polarity of its field determined by the *combined* effects of both shunt and series coils, it is evident that when used as a motor the current in the shunt will oppose that in the series coils. Hence, the *difference* between the magnetising powers of the two coils will determine the polarity and strength of the magnetic field. Such a machine is known as a *differentially-wound* motor.

*"Lead" of the Brushes of Motors.*—The self induction due to the armature of a generator chiefly determines the lead of the brushes. If it is great, and the field is weak, the lead will be considerable. If it is small, and the field be powerful, the lead will be small also. But in the case of a motor exactly the reverse is the case. Here the self induction, being in the reverse sense, tends to diminish the lead. When a motor is desired to run in a particular direction the lead must be determined to give, in that direction, the strongest mechanical effect. It the brushes be set with no lead the armature will be apt to run in either direction, as it may happen to be started, but without exerting its maximum effect. In cases where the motor is required to reverse its direction of running, by reversing the current (as is frequently done) the brushes must not be given any lead. There is, however, an element of uncertainty (in many cases) that the motor shall reverse its direction of turning upon a reversal of the current. It is immaterial whether (in the case of a series motor) the current is reversed in the armature or in the field magnet.

Although almost any type of continuous current dynamo may be used as a motor, yet makers usually produce specially built machines for this purpose. As a rule motors, especially if used for propelling vehicles, must be more heavily built than dynamos.

They are subject to greater strains, and the mechanical arrangement of the induction coils, the core and the shaft of the armature must be as solidly constructed as possible. This is especially true of the connections between the coils and the core. The wires are preferably sunk permanently, with hard insulation, in channels in the core, as in the Weston and the Westinghouse armatures. The core, if built of plates, must be properly keyed or "feathered" upon the shaft.

Many attempts have been made to render the armatures of motors waterproof. Lieut. Sprague, in the construction of his famous motor, has produced machines so perfect in this respect that they may, it is stated, be washed with a hose and water after the day's run under the street cars upon which they are employed. This implies that the whole of the electrical work is similarly waterproof.

## Electro Motor Governing.

Government or regulation by differential winding appears to be the most suitable method adapted to the case of motors. It has the great advantage that no breaks in the circuit are required. A great number of ingenious regulators have been invented in which the current is admitted to the circuit of the motor during a proportion only of the time of each revolution. The chief drawback of this system lies in the fact that break and make of circuit are necessary, involving a great deal of destructive sparking at the points of rupture.

The proportions between the shunt and series windings of the field magnets vary in different motors, but those expressed in Ayrton and Perry's formula have produced motors almost perfectly self-regulating. Let $S$ stand for the number of turns of the series coils, $Z$ for those of the shunt coil, $R_z$ for the resistance of the shunt, $R_a$ for the resistance of the armature, and $R_s$ for that of the series turns (expressed in ohms) then:

$$\frac{Z}{S}=\frac{R_z}{R^a + R_s}.$$

The Sprague motors, that have been so successfully used in America, are wound according to this rule.

A method of governing applicable to the case of a motor with more than one pair of poles has been proposed by Professor S. P. Thompson. He uses as field magnets a double set of poles set at different angles with respect of the brushes of the motor. One pair of magnetic poles, having a certain lead, is actuated by series coils; the other pair, having a different lead, by shunt coils. When both shunt and series are working there will be a resultant pole having some intermediate lead. If the load of the motor is diminished, it will tend to run faster, increasing the current in the shunt part,* decreasing it in the series part, and therefore altering the effective lead and preventing the increase of speed.

*Inferior Efficiencies of the Compound-Wound Motor.*—It can easily be shown, however, that in point of efficiency a differentially wound motor must be inferior to a motor either plain series or shunt wound. This shortcoming is due to the fact that the energy required to magnetize the field magnet is greater in the case of employing two opposing coils, as when the series and shunt machines are combined in one. The great advantages, however, of the differential method of winding in motors, combined with the fact that the loss due to the opposing coils is always relatively small, will probably lead to the almost universal adoption of compound motors for regular running. The energy consumed in magnetizing the field is always a small proportion of that supplied at the terminals, series or shunt, of the motor, and even if the opposing coils in a compound motor consume fifty per cent. more it is still advantageous to employ this method of regulation.

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* This effect is due, as previously explained, to the increased counter electromotive force of the armature coils, increasing as it does with the velocity—it may, therefore, be regarded as equivalent to an increased resistance of those coils.

*Non-starting of a Shunt Motor.*—A shunt motor, without any auxiliary starting arrangement, may refuse to begin to rotate of itself if standing idle when the current is switched on. This defect is due to the fact that the current, finding a path of comparatively low resistance through the armature as compared with the shunt windings, flows almost entirely in that path. Only a small proportion of the current, therefore, flows in the shunt. The lower the armature's resistance the less current will flow in the shunt, and there will be little or no magnetism in the field. When, however, the motor is started, the revolution of the armature immediately sets up in its coils an opposing or counter electromotive force, as before explained. This being, in the case in point, equivalent to increasing the resistance of the armature, a proportionately larger current will at once flow in the shunt, and the field magnet will become energised. As the speed increases more and more current will be diverted round the shunt, because the counter current of the armature is nearly proportional to the speed. The greatest effect will therefore be exerted by the motor when the magnets are magnetized to saturation.

### Typical Motors.

The first dynamos used in this country as motors were series-wound Gramme and Siemens machines. These types are still to a considerable extent employed for motive power purposes.

*Immisch's Motors.*—These motors attracted a great deal of attention at the recent Exhibitions, chiefly on account of their high efficiency. They are built with both ring and drum armatures. The ring type appears to be reserved for small motors, under two-horse power. The field magnet of the larger type is of the Siemens horizontal pattern, with four coils, but, unlike it, is not divided into parallel bars. The pole pieces are solid. The drum armature is built upon a core of iron discs with asbestos insulation. At intervals along the length of the core occur thick discs having driving horns. These form longitudinal channels for the reception of the coilings. The commutator bars are arranged alternately in two groups, side by side. By the contact of a pair of brushes, or a single broad brush, the coil that reaches the neutral point or that connecting the front bar to the back bar is cut out of circuit. The inventor states that this is equivalent to employing an ordinary winding and collector and a pair (connected as one) of brushes on each side, the brushes of each pair being set apart the width of a bar. This arrangement is said to obviate changing the lead of the brushes and to diminish cross magnetizing. This motor has already been used extensively in the propulsion of street cars. They have also been employed for hoists, but their most important application appears to be to the case of pumping in mines. In many instances the Immisch motors have displaced the best system of compressed air power transmission for that purpose.

*Ayrton & Perry's Motor.*—This motor is remarkable in being of an extremely compact construction. It is of great power in proportion to its dimensions and weight. Further it is remarkable inasmuch that the field magnet rotates while the armature remains a fixture. The armature is made in the form of an elongated Pacinotti ring. It is built up from toothed discs, so that the teeth form longitudinal channels along the length of the core, into which the coils are wound. This part is a fixture and forms the outer casing of the machine. The field magnet is constructed in the form of a shuttle armature, with extending polar shoes. While the rings through which the current is passed to the armature are fixed, the brushes leading it into the rings rotate with the shaft and the field magnet. These motors have been used for various purposes.

*Sprague's Motors.*—The application of the Sprague motor in America to the propulsion of vehicles is considerable. The machines assume various forms to adapt them to the particular class of work to be done. One of the best is that generally used for stationary purposes. It is in the form of a bipolar dynamo. The field magnet is in the main similar to that of the Sautter-Lemonnier dynamo (Fig. 82, p. 275), with this difference that in the Sprague motor the magnet cores are cylindrical. The centre of gravity of the rotating portion is thus kept well down, and the bearings being in consequence low the whole is adapted for steadiness in running at high velocities. The armature is of the drum type. These motors are usually differentially wound, and are therefore adapted for automatic regulation. They run at a constant speed upon constant potential circuits. In the case of arc lighting circuits simple series-wound motors are preferred.

*Crocker-Wheeler Motor.*—This type has become very popular in the United States, and it is used in this country for various purposes. Its construction is of a high order of merit. The field magnet is of the bipolar type as in the Kapp dynamo (Fig. 90, p. 287), but with cylindrical cores. The mounting of the armature is also of the overtype. The collecting cylinder is long and gives sufficient space to shift the brushes to fresh positions of contact. There are two pairs of brushes, or one pair in duplicate, so that any one brush may be removed and trimmed without interrupting the current.

"*C and C*" *Motor.*—The application of this famous motor has been very extensive, especially in America. It consists of a field magnet similar in design to Fig. 82 (p. 275), but having the coil portion of the core curved inwards to the arc of a circle. The armature is of the ring type and is mounted as near the base as practicable. These motors are built either series wound for use on arc circuits or differentially wound for running upon constant potential circuits. They are made in sizes from $\frac{1}{8}$th horse-power to 30 horse-power.

*Motors in England.*—Most of the applications of electromotors in England have been in connection with the heavier branches of engineering. These have been, hitherto, electric traction, as railways and tram cars, and hauling and pumping in collieries. With the exception of the Immisch motor, which is specially built for transforming electric current into motive power, few firms build machines specially for motor work. On the other hand, the ordinary dynamos of English manufacture form the most efficient motors, and many of them have been applied to the conversion of electricity into power with but little alteration. The Crompton, the Edison-Hopkinson, the Elwell Parker, the Kapp, and numerous other English built dynamos may be used either as generators or motors, and there is this advantage in that feature that at any time a motor may be turned into a dynamo, since there are no special fittings rendering it unfit for that work. The best example of the electrical railway in this country (the City and Southwark Subway, London, is run by motors consisting of Edison-Hopkinson dynamos. The spread of networks of electric mains in the larger towns will doubtless, as has been the case in America, lead to the extensive utilisation of electromotors for many minor purposes requiring an expenditure of energy under five horse-power. Both coal and gas are, however, so inexpensive in this country, and gas motors have attained to such a pitch of perfection, that the introduction of the electromotor will no doubt be thereby materially retarded.

# INDEX.

ABBÉ DAL NEGRO'S machine, 6
Activity, external, curves of, 224
Air spaces, resistance of, 195
  gaps, width of and the E.M.F., 306
Alignment of bearings in dynamo, 248
Alliance dynamo, the, 10
Alteneck's armature, 16
Alternator, Siemens', 274
  in parallel, 235
  periodicity of, 236
  phase of, 236
  synchronizing of, in parallel, 239
  "in step," 239
  compensation, excitation of, 242
  and transformers, 243
  Kapp's, 291
  Ferranti's, 293
  Thomson-Houston, 313
Ampère turns in exciting coils, 71
  determination of, 198
Apparatus, Dal Negro's, 6
Armature, Sturgeon's, 8
  shuttle, 11
  shuttle, Siemens', 11
  Pacinotti's, 14
  Gramme's, 15
  Alteneck's, 16
  the simplest, 24
Armature, nature of the, 36
  wire, insulated, 75
  fall of potential in, 193
  core, Kapp lines in, 193
    dimensions of, 193
  reluctance of, 197
  handling, 249
  Kapp's multipolar, 284, 289
  Westinghouse's, 317
Arc lighting, series dynamos in, 246
Asbestos insulation of collector, 257
Attrition of collector cylinder, 249
Ayrton & Perry's motors, 341

BATHS or vats in series, 268
  Bearings, alignment of, in dynamo, 248
Bell ringing, magneto machine for, 12
Belting of dynamos, 252
Best collection, point of, 259
Bipolar dynamo, Siemens', 274
Board of Trade unit, 214
Brett's improvements of 1848, 10
Brushes, nature of the, 26
Brush-shifting regulation, 200
    effects of 201
  position of, 259
Brush's "teazer" winding, 267
  dynamo, 278
Burnt coils, 256

- CALCULATION of exciting coils, 53
- Capacity of the main and shunt coils, 199
- Characteristic curves, 219
- "Characteristics," method of drawing, 221
  - horse power, 223
- Characteristics of shunt dynamo, 226
  - compound ditto, 227
  - magnetization, 229
- Chief parts of the dynamo, 20
- Circuit interrupter, 7
  - closers for testing, 254
  - opener for plating dynamo, 267
- Clark's machine, 6
- Crocker-Wheeler motors, 342
- Coils, induction, combined with magnet, 9
  - exciting, calculation of, 53
    - details of, 70
    - depth of, 71
  - short circuited, 256
- Collector, nature of the, 25
  - brushes, nature of, 26
  - or commutator for drum armature, 26
  - re-turning of, 260
  - worn, 260
  - bars, short circuiting of, 257
- Commercial efficiency of dynamo, 214
- Common form of electro-magnet, 42
- Commutator, earliest form of, 7
  - nature of the, 25
  - or collector for drum armature, 26, 37
  - treatment of, 249
  - attrition of, 249
  - worn, 260
  - re-turning, 260
- Compensation excitation of alternator, 242
- Composite field, regulation by, 211
  - wound dynamo, 313
  - winding, Thomson-Houston, 316
- Compound winding, early conception of, 13, 49
  - diagram of, 50
- Compounding, regulation by, 209
- Compound dynamo, 217
  - in glow lighting, 244
  - in parallel, 234
- Conditions of working, essential, 37
- Conductivity of insulated wire, 75
- Connecting up new dynamo, 250
- Continuous current dynamo, the earliest, 5
- Constant potential working, development of, 18
  - current, regulating, 212
- Counter-direction current from plating vat, 266
- Course of the current in the dynamo, 250
- Current, non-fluctuating, 14
  - causing magnetic field, 31
  - density in magnetic coils, 72
  - course of the, in dynamo, 250
  - reverser for testing, 254
  - in electro-plating, 263
- Cut-outs at dynamo, 258
- Curves of magnetic lines, 31
  - magnetization, 55
  - characteristic, 219
  - method of drawing, 220
  - horse-power, 223
  - of external electrical activity, 224
  - representing internal resistance, 225
  - variable speed, 225
  - from compound dynamo, 227
  - magnetization, 286
    - from Kapp's dynamo, 290

- DAL NEGRO'S apparatus, 6
  - Dead break fault, 255
- Definition of the word "dynamo," 1
- Depth of exciting coils, 71
- Deptford, dynamos at, 294
- Density of current in magnet coils, 72
  - electro-plating, 264
- Desroziers' dynamo, the, 276
- Determination of the exciting current, 198
- Details respecting exciting coils, 70
- Development of the self-energizing principle, 13
  - of constant potential working, 18
- Diagram of Gramme ring armature, 16
  - separate excitation, 44
  - shunt winding, 47
  - series winding, 45
- Diffusion of the magnetic lines, 32
- Dimensions of field magnet core, 194
  - armature core, 195
- Direct-current dynamo for lighting, Thomson-Houston, 310
- Disc dynamo, Faraday's, 5
- Dissimilar dynamos yoked together, 235
- Divertor, magnetic, 242
- Drawing curves, 221
- Driving by rope gear, 252
- Drum armature, collector or commutator for, 26
- Dynamo, definition of the word, 1
  - a motor, 2
  - evolution of the, 2
- Dynamic electricity, early history of, 2
- Dynamo, the first, 4
  - earliest attempts to construct, 4
    - continuous current, 5
  - Woolrich's early, 9
- Dynamo, Brett's, of 1848, 10
  - the Alliance, 10
  - development of the self-energizing principle in, 13
  - compound, early invention of, 13
  - shunt, early invention of, 14
  - electric machine, origin of the term, 14
  - Pacinotti's, 15
  - improvements in the, 16
    - in, by Sir William Thomson, 17
    - in, by Gordon, 17
  - elements of the, 20
  - chief parts of the, 20
  - supplementary parts of the, 21
  - simplest conception of a, 23
  - "overtype" of, 28
  - lines of force in, 35
  - magnetic field in, 36
  - field magnets, 41
  - separate exciter of, 44
  - series, winding, of, 45
  - shunt, winding of, 46
  - compound winding of, 49
  - in series and parallel, 230
  - in electric lighting, 241
  - and exciter on one shaft, 243
  - compound, in incandescent lighting, 245
  - shunt-wound, in incandescent lighting, 245
  - series, in arc lighting, 246
  - connections of, 250
  - starting and belting, 252
  - overloaded, 261
  - for electro deposition, 262
  - typical, 271
  - Siemens', 274
  - Sautter-Lemonnier, 274
  - Rechniewski's, 276
  - the Desroziers, 276

Dynamo of the Société alsacienne de Constructions Mechaniques, 277
  Brush's, 278
  Edison's, 279
  Edison-Hopkinson, 279
  Elwell Parker, the, 281
  Kapp's, 283
    alternating current, 291
  Ferranti's, 293
  at Deptford, the, 294
  Firth's, 305
  Kennedy's, 307
  Paterson & Cooper's, 309
  the sphere armature, 310
  Thomson-Houston alternating current, 313
  composite wound, 316
  Westinghouse's, 316

EARLIEST magneto machines, 4
Early type of magneto machine, 7
    commutator, 7
Edison's dynamo, 279
Efficiency and output, 213
  of dynamo, commercial, 214
  electrical, 214
Electro motor, nature of, 2
  magnet, common form of, 42
    formulæ, 56
Electrical efficiency, 214
  effect of dynamo, total, 214
  activity, variation of, 216
Electric lighting, dynamos in, 241
Electro-plating, "intensity and quantity" in, 262
  depositing dynamos, 262
Electro-plating dynamos, 262
  E.M.F. required in, 263
  current required in, 263
Electro copper ore refining, 269
Electrolysis and copper ore, 269
Electro motor, magnetic principles of the, 330
Elements of the dynamo, 20
Elementary principles, the, 30
Elwell Parker dynamo, 218
E.M.F. lost internally, 216
  in electro-plating, 263
Essential conditions of working, 37
Evolution of the dynamo, 2
Excitation, separate, 44
Exciting coils, calculation of, 53
    details respecting, 70
    ampère-turns of, 71
    depth of, 71
  current, determination of, 198
Excitation, compensation of alternator, 242
Exciter and dynamo upon one axis, 243
Excite, failure to, 257
Experiment, Faraday's iron ring, 4
  with Firth's dynamos, 306
External electrical activity, curve of, 224

FAILURE to excite, 257
    of residual magnetism, 255
Fall of potential in armature, 193
Faraday's iron bar experiment, 3
  experiments of 1831, 3
  disc dynamo, 5
Faults of field magnets, 80
Faults, testing for, 252
  in dynamo, 252
  localization of, 255
Faulty cut-outs, 258
Ferranti's alternators, 293
  dynamos, 293
  alternator in working order, 295
    open, 296
    bobbins of, 300
    armature, 301